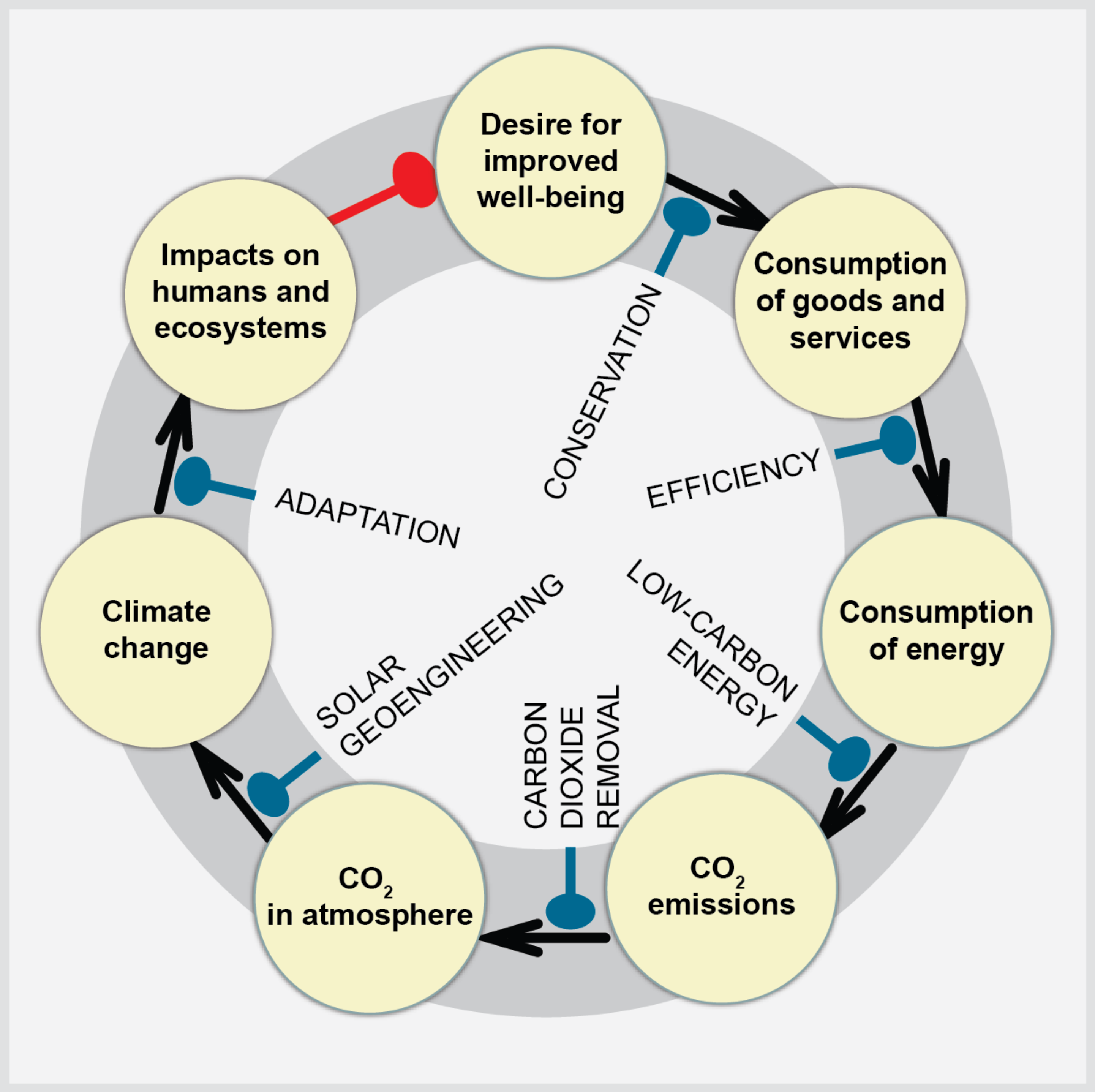
GCEP

Energy Tutorial:
Geoengineering 101

GCEP RESEARCH SYMPOSIUM 2012 | STANFORD, CA

Ken Caldeira

Staff Scientist – Carnegie Institution
Professor (by courtesy) – Environmental Earth System Science
Stanford University



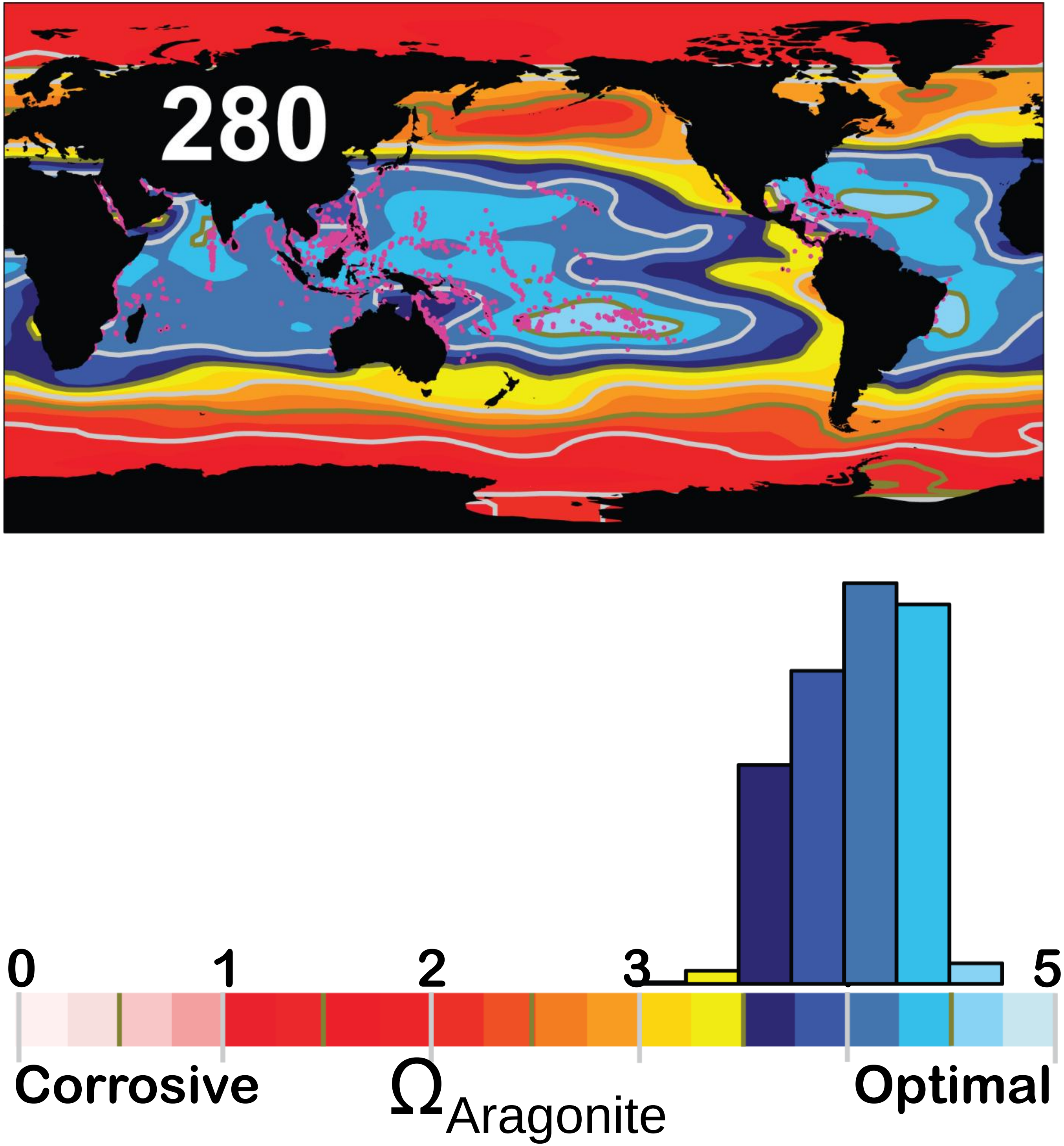
Caldeira, Cao, and Bala, submitted

Distribution of corals and ocean acidification

Carbon dioxide level,

Coral reef distribution,

and chemical conditions helping drive reef formation



Cao and Caldeira, 2008

Carbon dioxide level,

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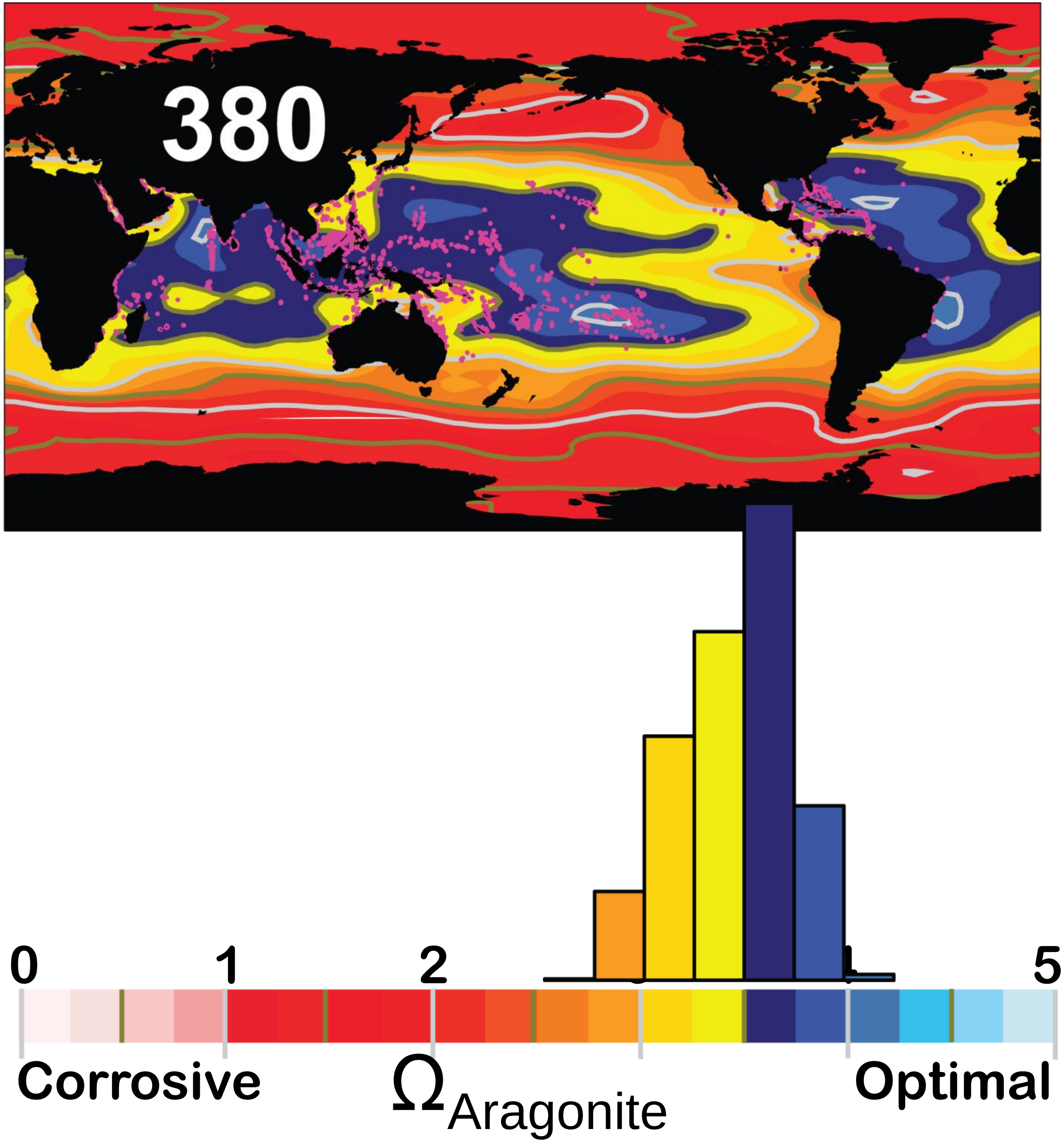

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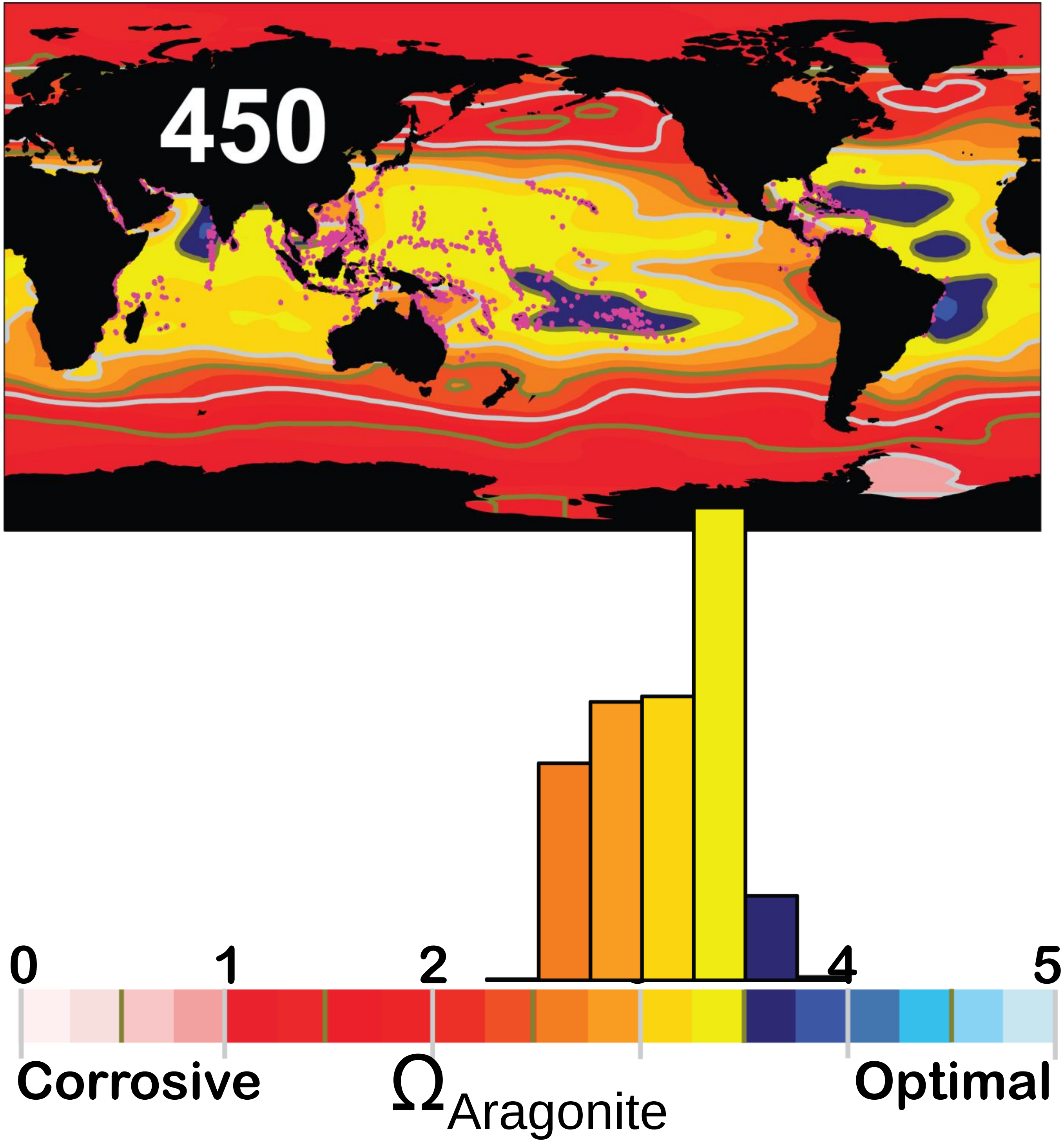

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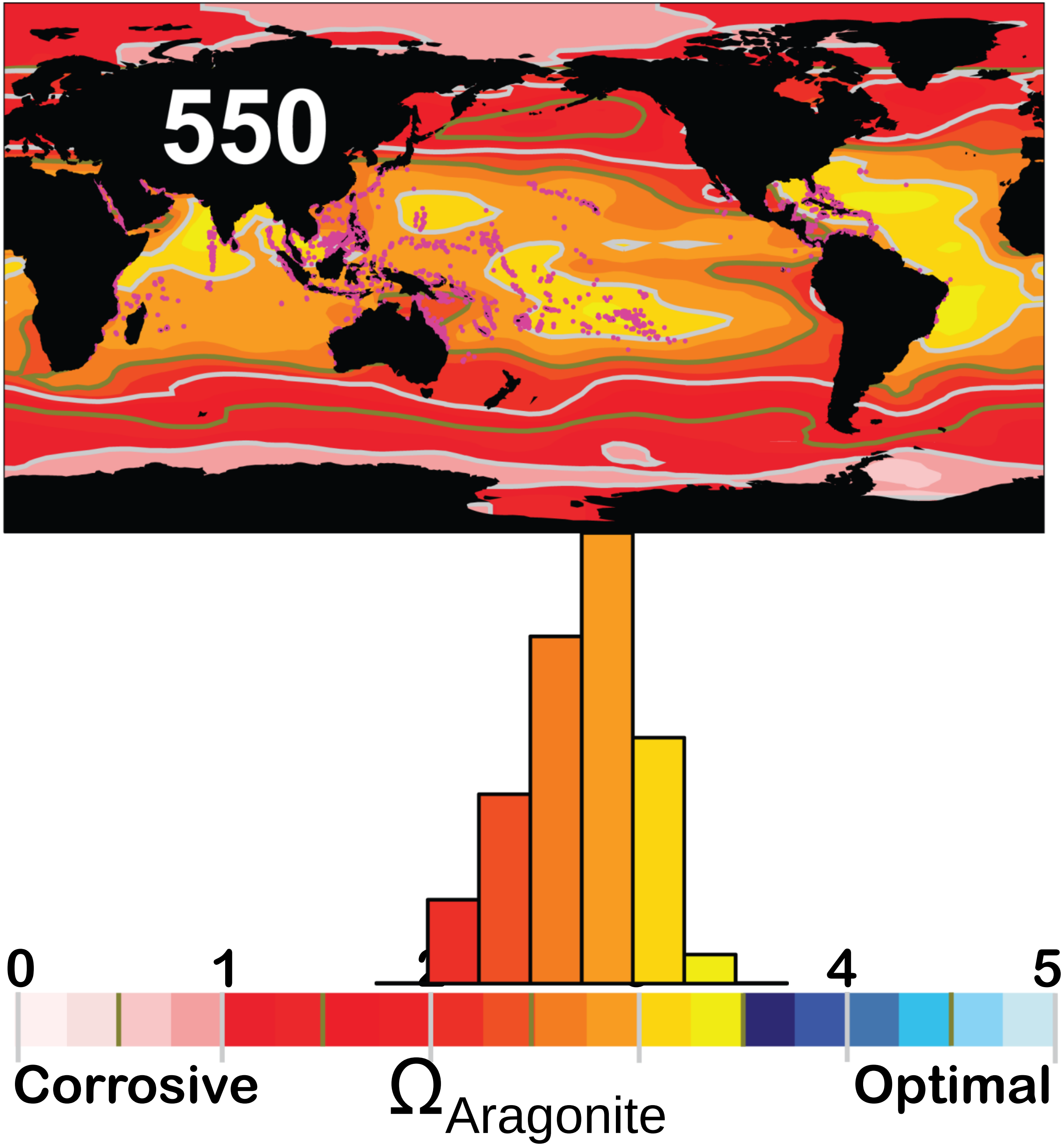

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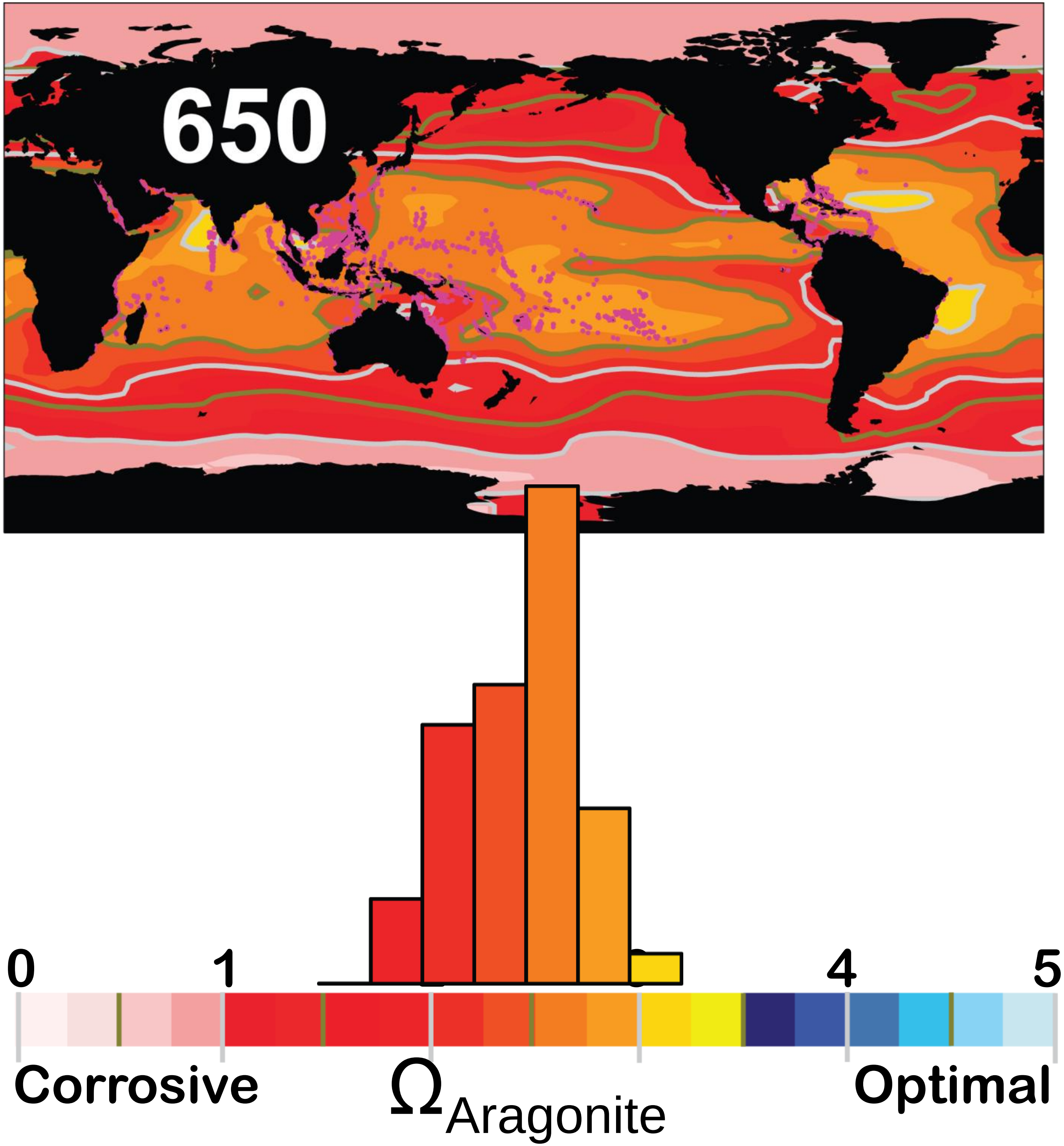

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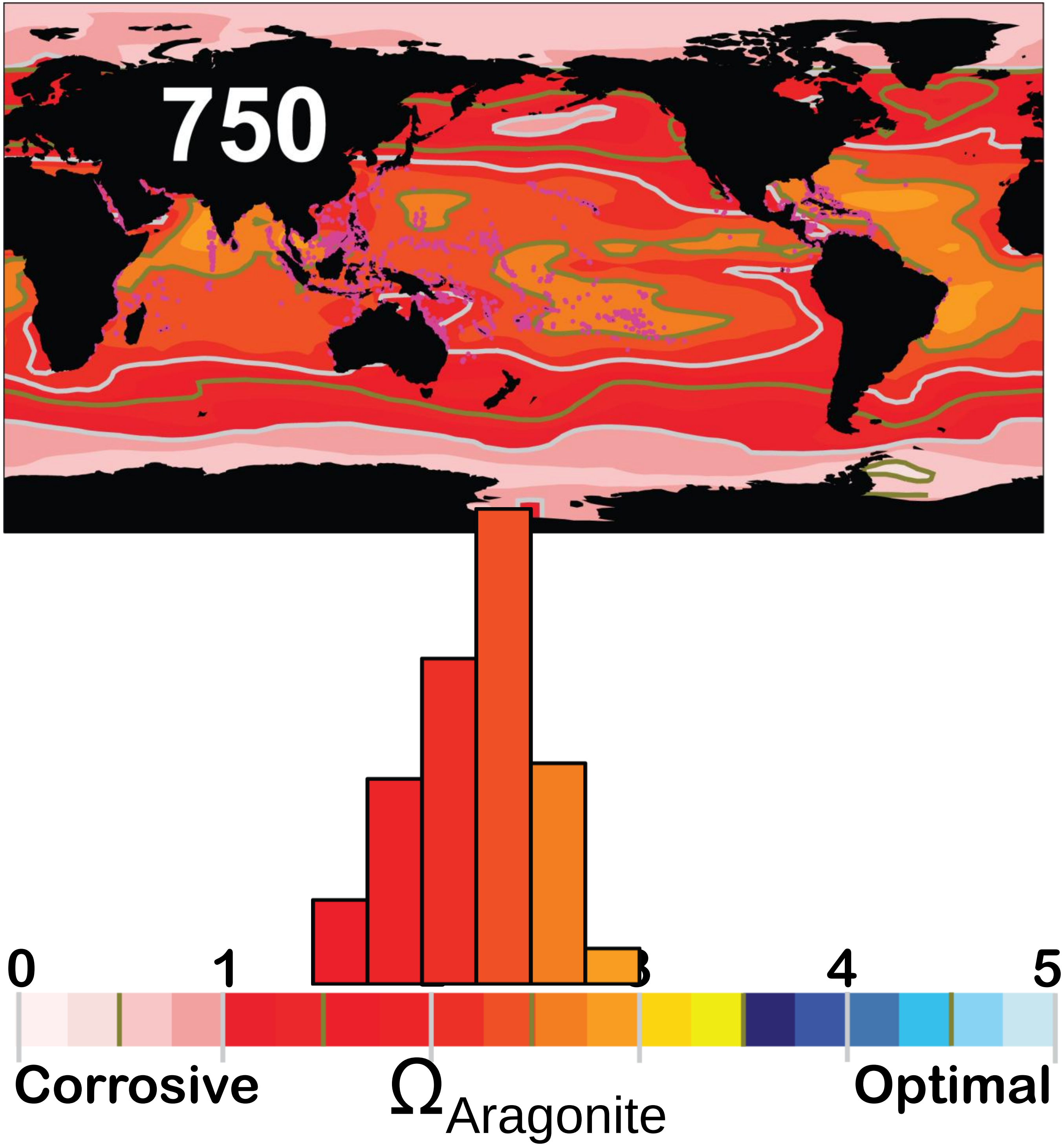
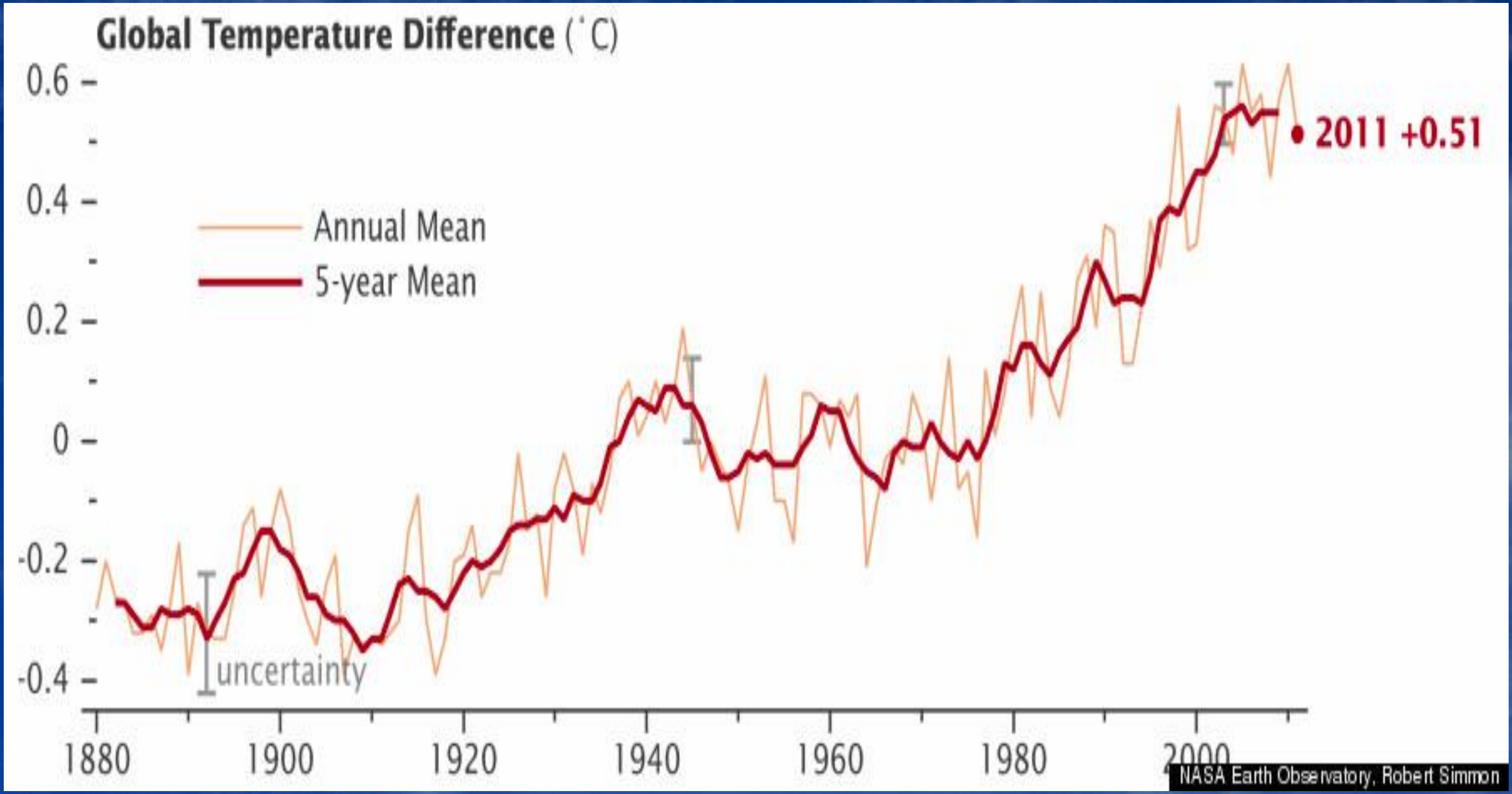


Cao and Caldeira, 2008

Photo: sookietex

Global mean temperature for the past 136 years



Probability of 2040-2060 summer being hotter than hottest on record

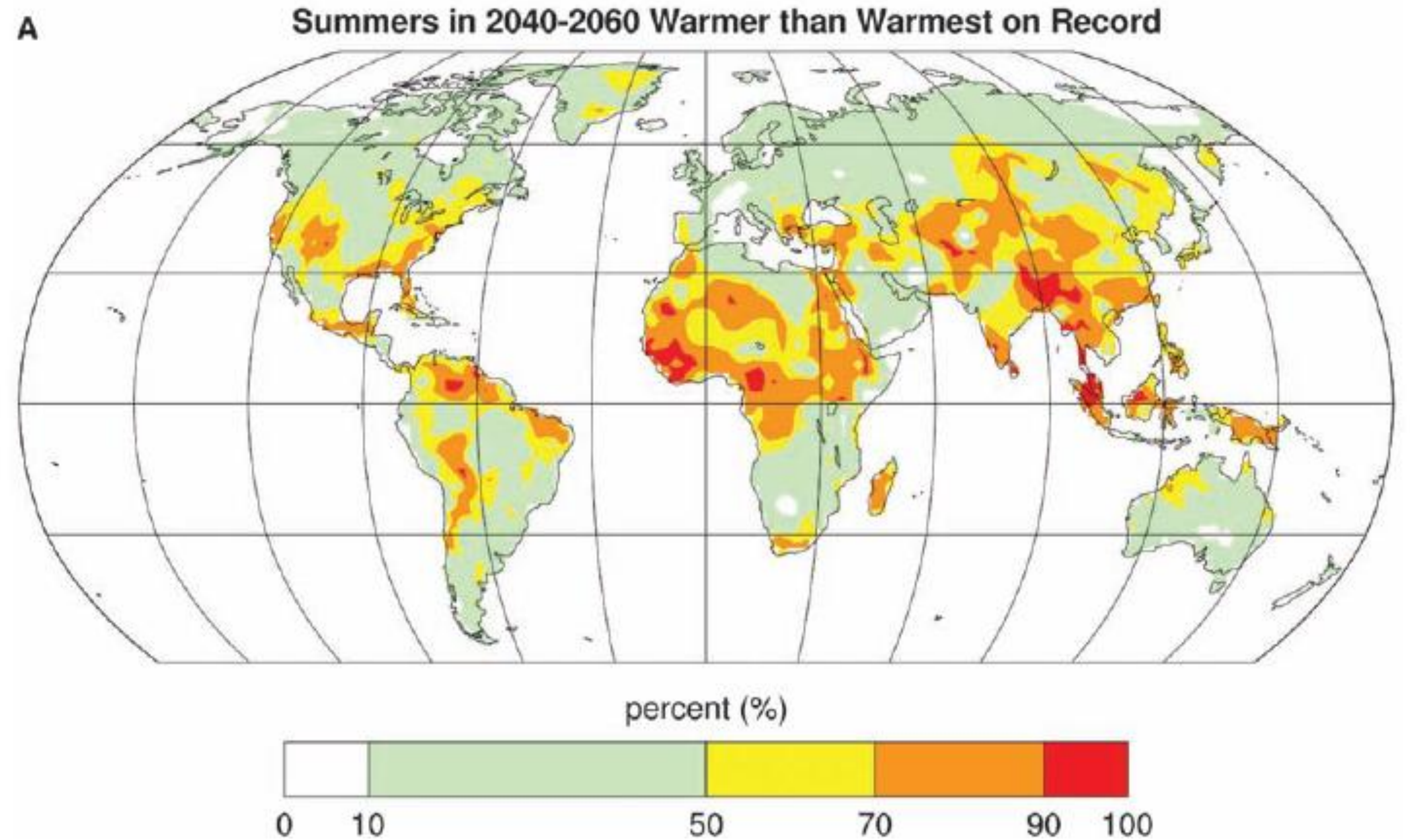
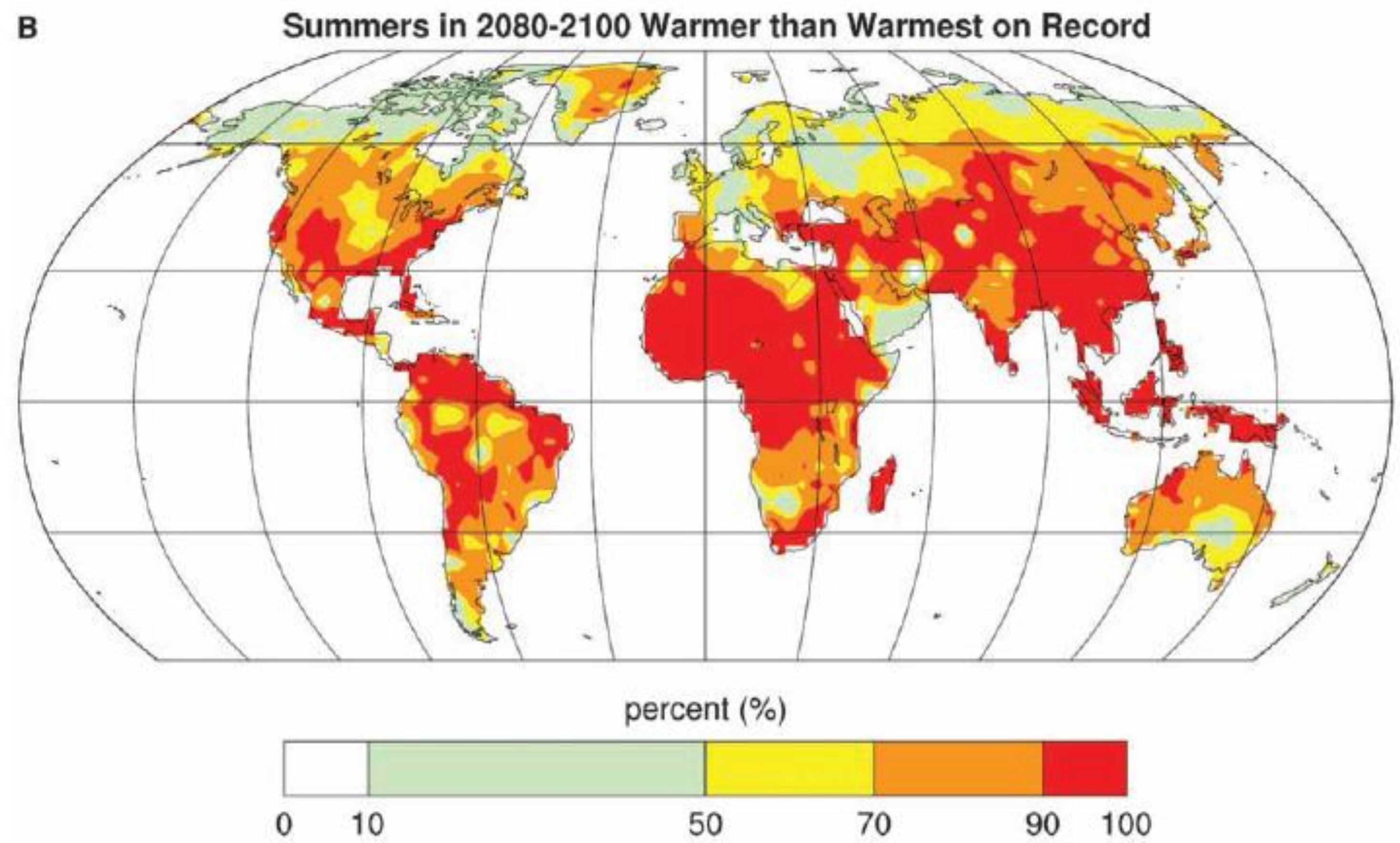


Fig. 3. Likelihood (in percent) that future summer average temperatures will exceed the highest summer temperature observed on record (**A**) for 2050 and (**B**) for 2090. For example, for places shown in red there is greater than a 90% chance that the summer-averaged temperature will exceed the highest temperature on record (1900–2006) (*22*).

David. S. Battisti[1] and Rosamond L. Naylor[2] 9 JANUARY 2009 VOL 323 **SCIENCE** www.sciencemag.org

Probability of 2080-2100 summer being hotter than hottest on record



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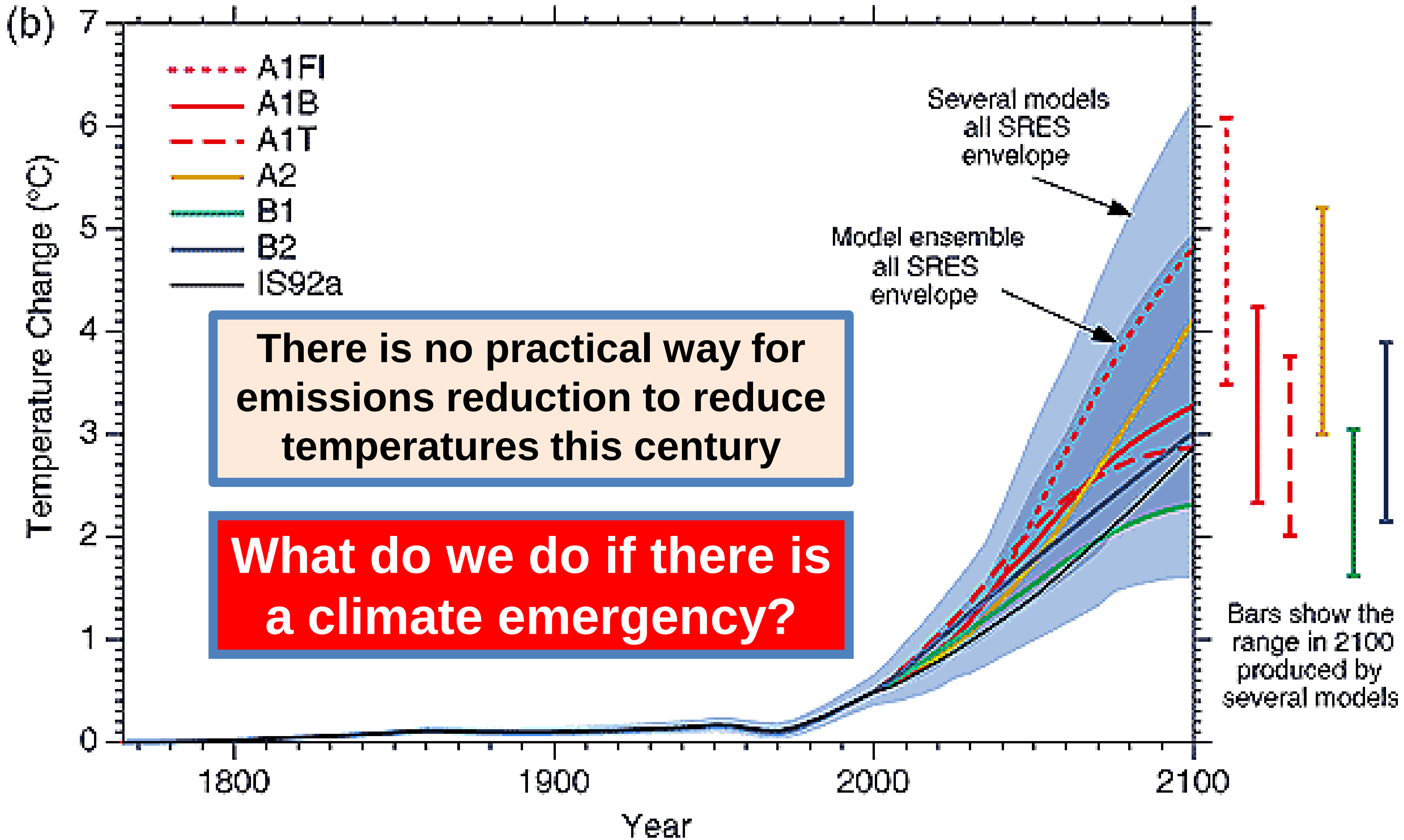
Temperatures continue to increase throughout this century in every plausible emissions scenario



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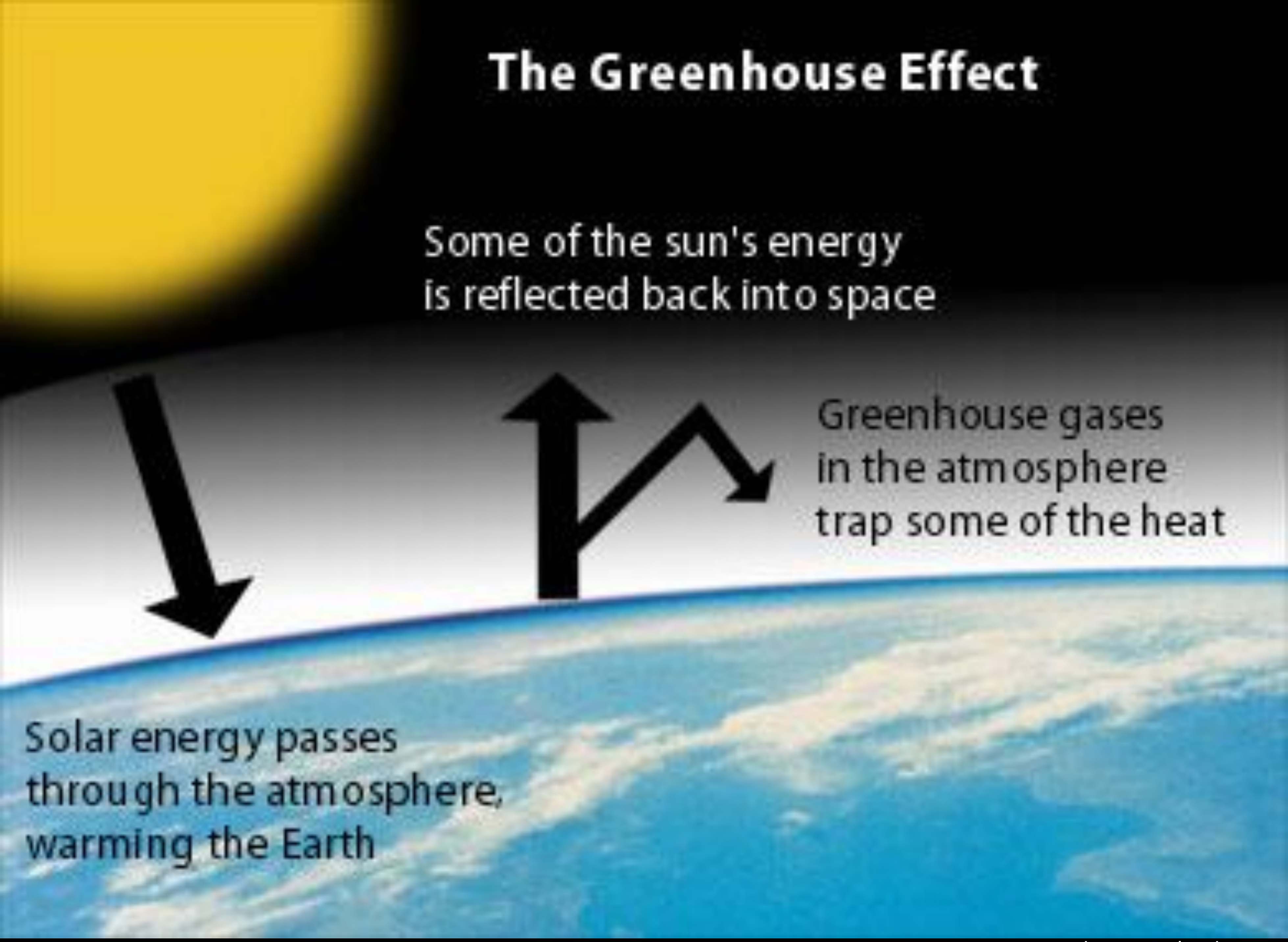
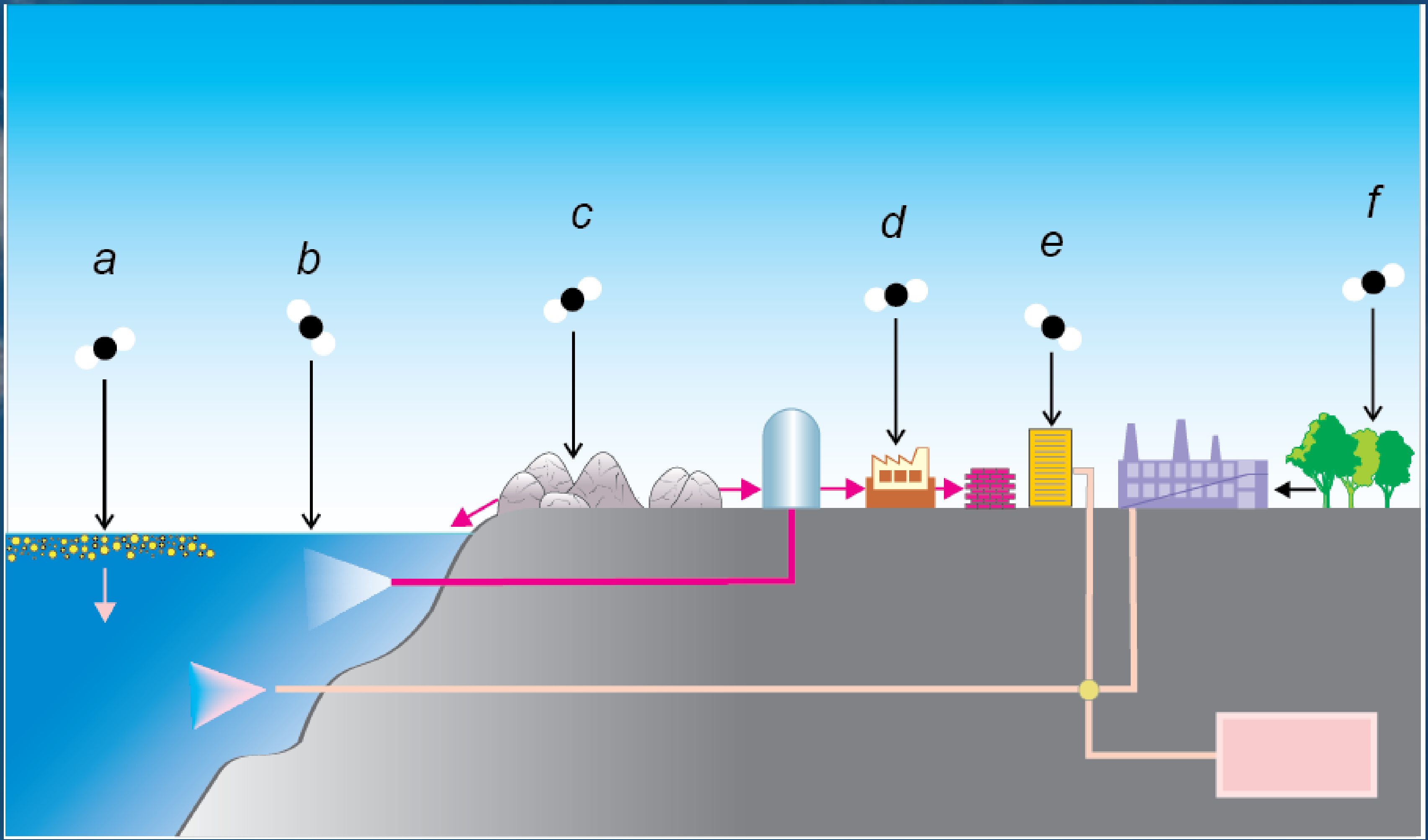
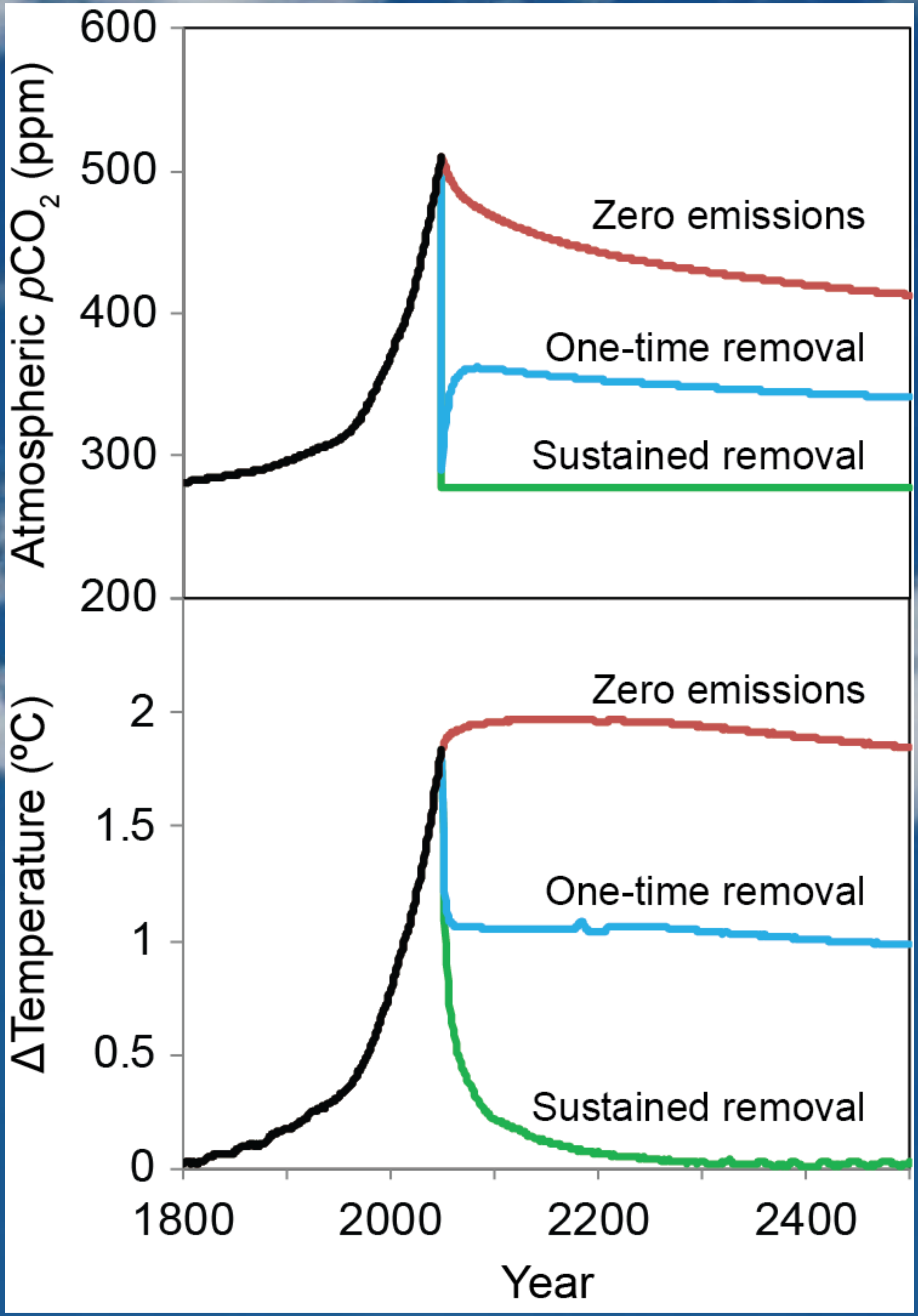

The Greenhouse Effect
Some of the sun's energy
is reflected back into space
Greenhouse gases
in the atmosphere
trap some of the heat
Solar energy passes
through the atmosphere,
warming the Earth

Can carbon dioxide be removed from the atmosphere?



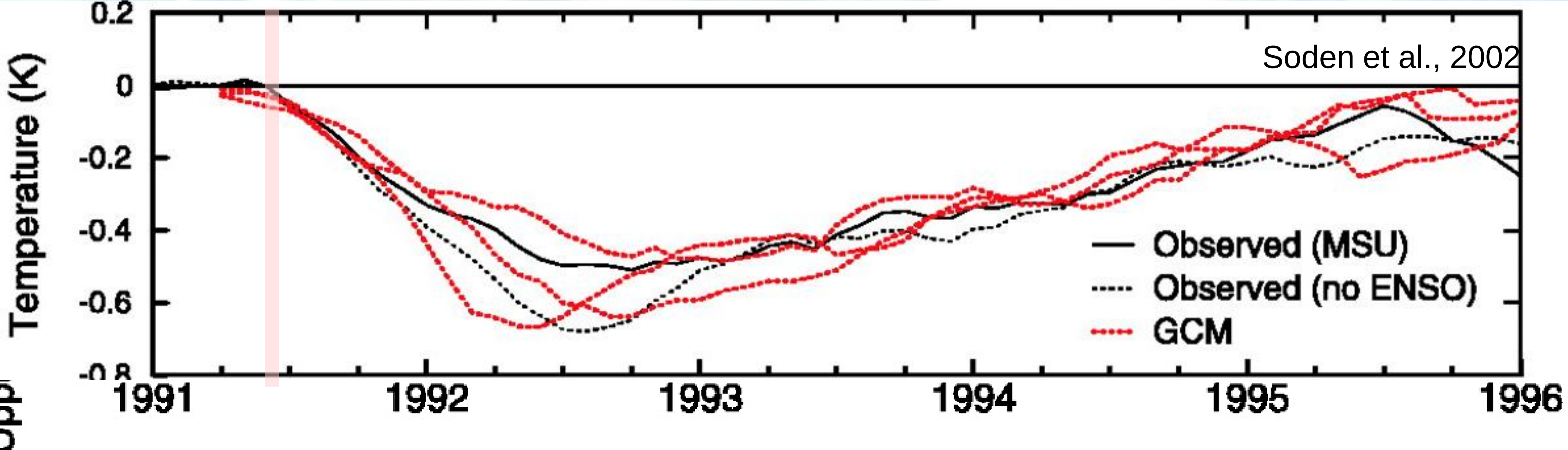
Caldeira, Cao, and Bala, submitted



If we removed all excess CO_2 from the atmosphere today, that would offset only about half the warming

Cao et al 2011

Mt. Pinatubo, 1991



Can sunlight be deflected away from the Earth?

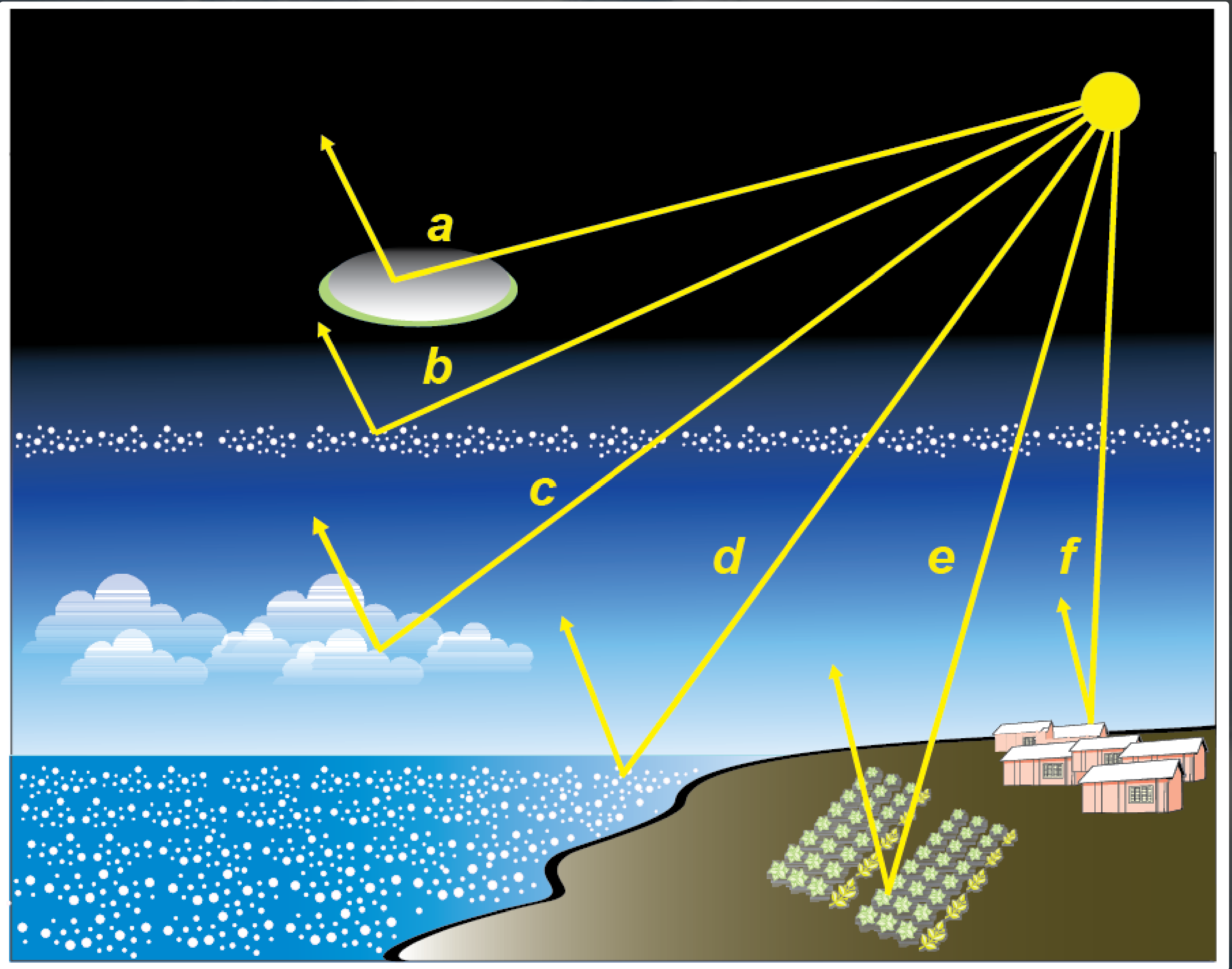


Photo: Sharee Basinger

Caldeira, Cao, and Bala, submitted

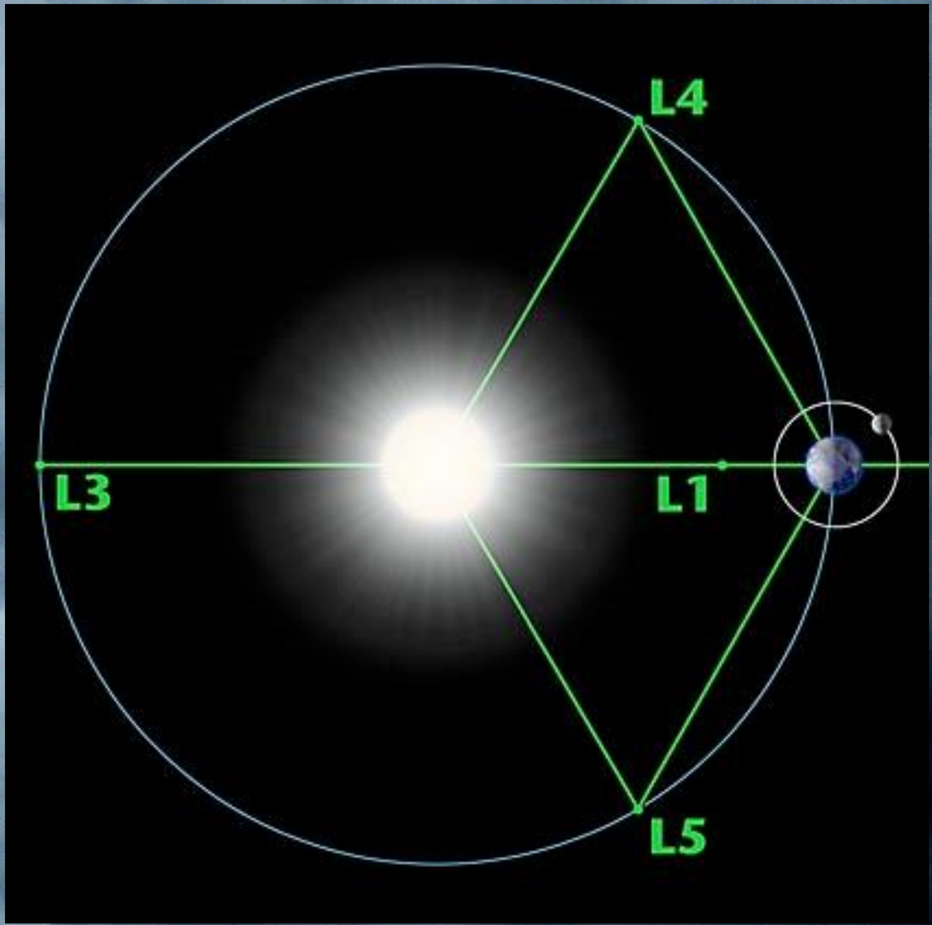
Sunlight deflection approaches

Space reflectors

Stratospheric aerosols

Cloud albedo

Surface albedo
- **Desert**
- **Urban**



www.tau.ac.il

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Sunlight deflection approaches

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Sunlight deflection approaches

Space reflectors

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Cloud albedo

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Desert

Urban

Mark Brodie, KJZZ

Sunlight deflection approaches

Space reflectors

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Cloud albedo

Surface albedo

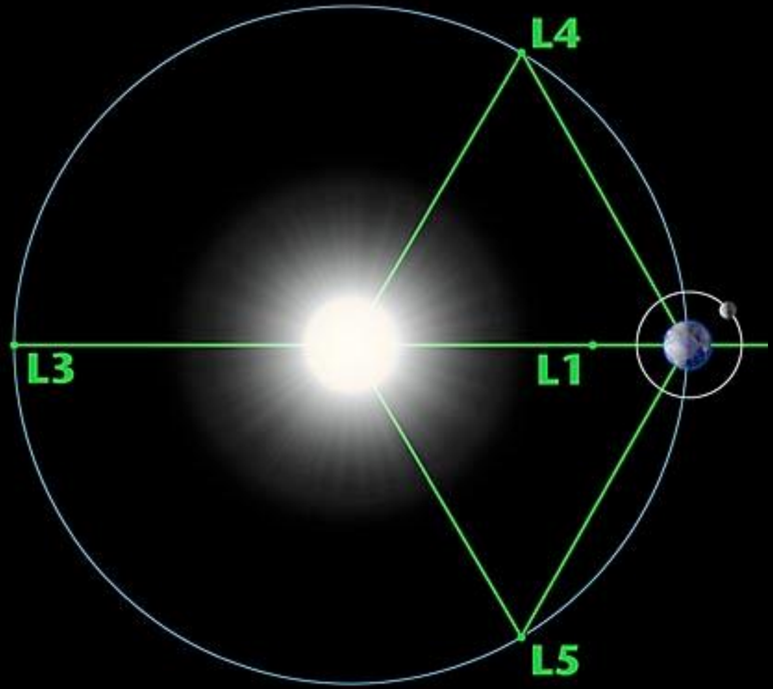
- Desert
- Urban

Sunlight deflection approaches

- Space reflectors
- Stratospheric aerosols
- Cloud albedo
- **Surface albedo**
  - Desert
  - **Urban**

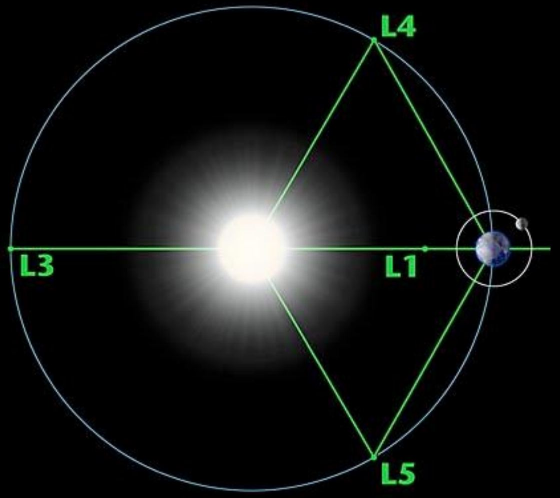
Rate of radiative forcing increase

- Each doubling of CO_2 traps ~2×10^{15} W
- To counteract a doubling of CO_2 over 100 years, we would need to be satellites between the Earth and Sun at a rate of 2.4 $km^2\ hr^{-1}$



Thin/small is the answer

- To compensate for a CO_2 doubling,
  - Disk area (out in space)
    - you need 2×10^6 km^2 area
  - Spherical area (in atmosphere)
    - you need 8×10^6 km^2 area
      volume @ 0.1 μm = 0.0008 km^3



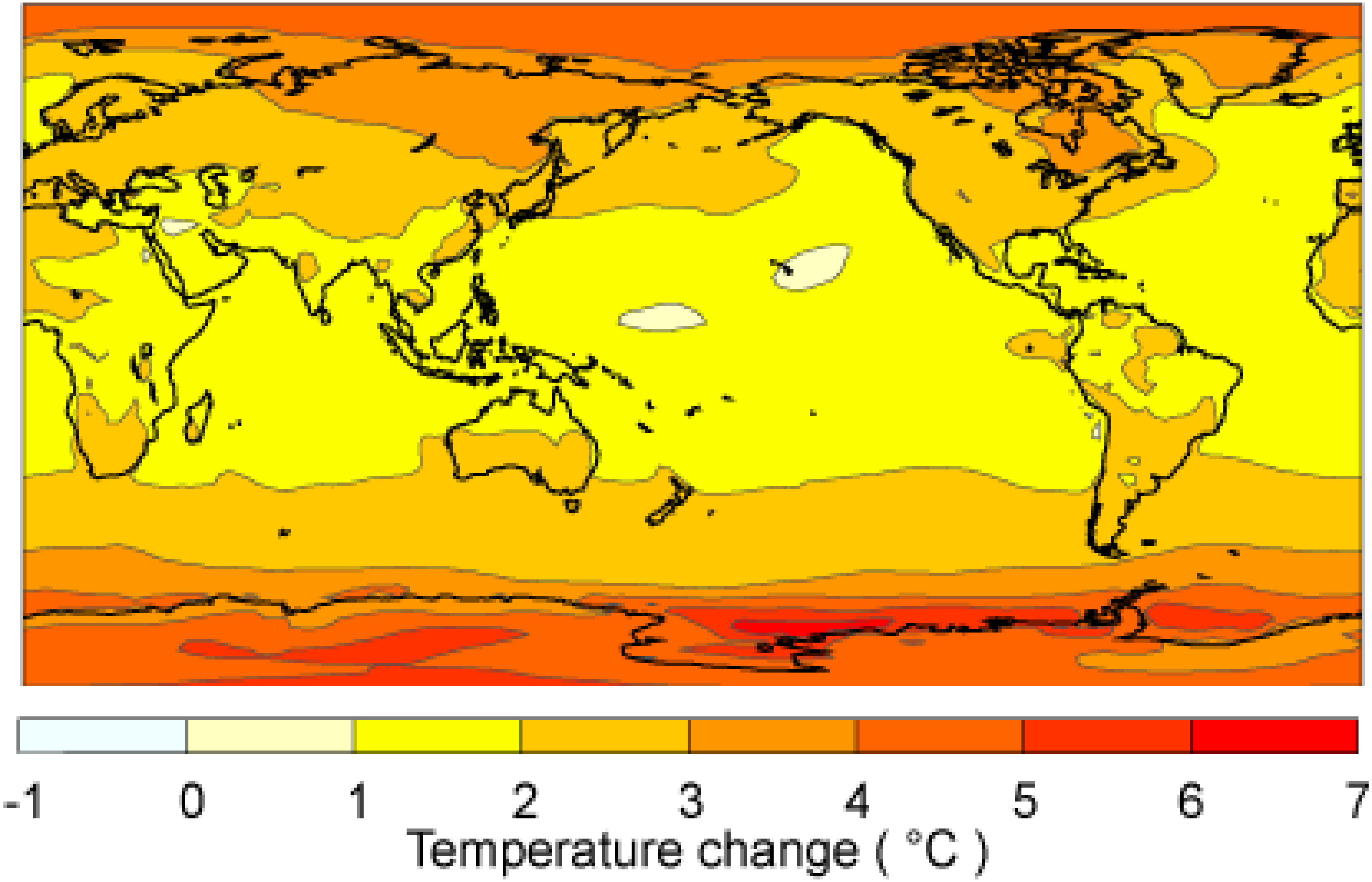
This is equivalent to a cube of less than 100 m on a side.

About 25 liters per second

Low direct costs of placing aerosols in stratosphere

Economist 2010

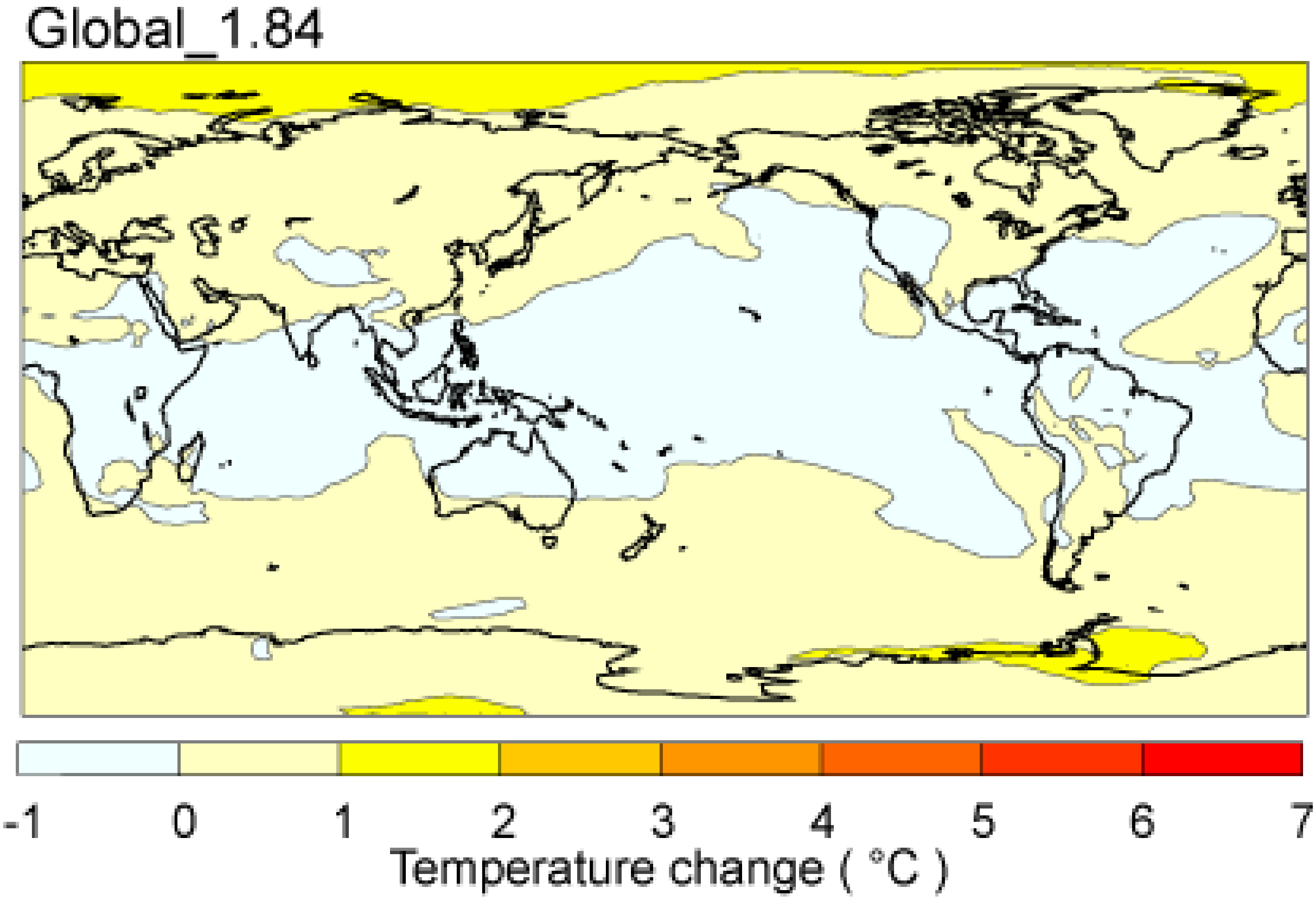
$2xCO_2$



Caldeira and Wood, 2008

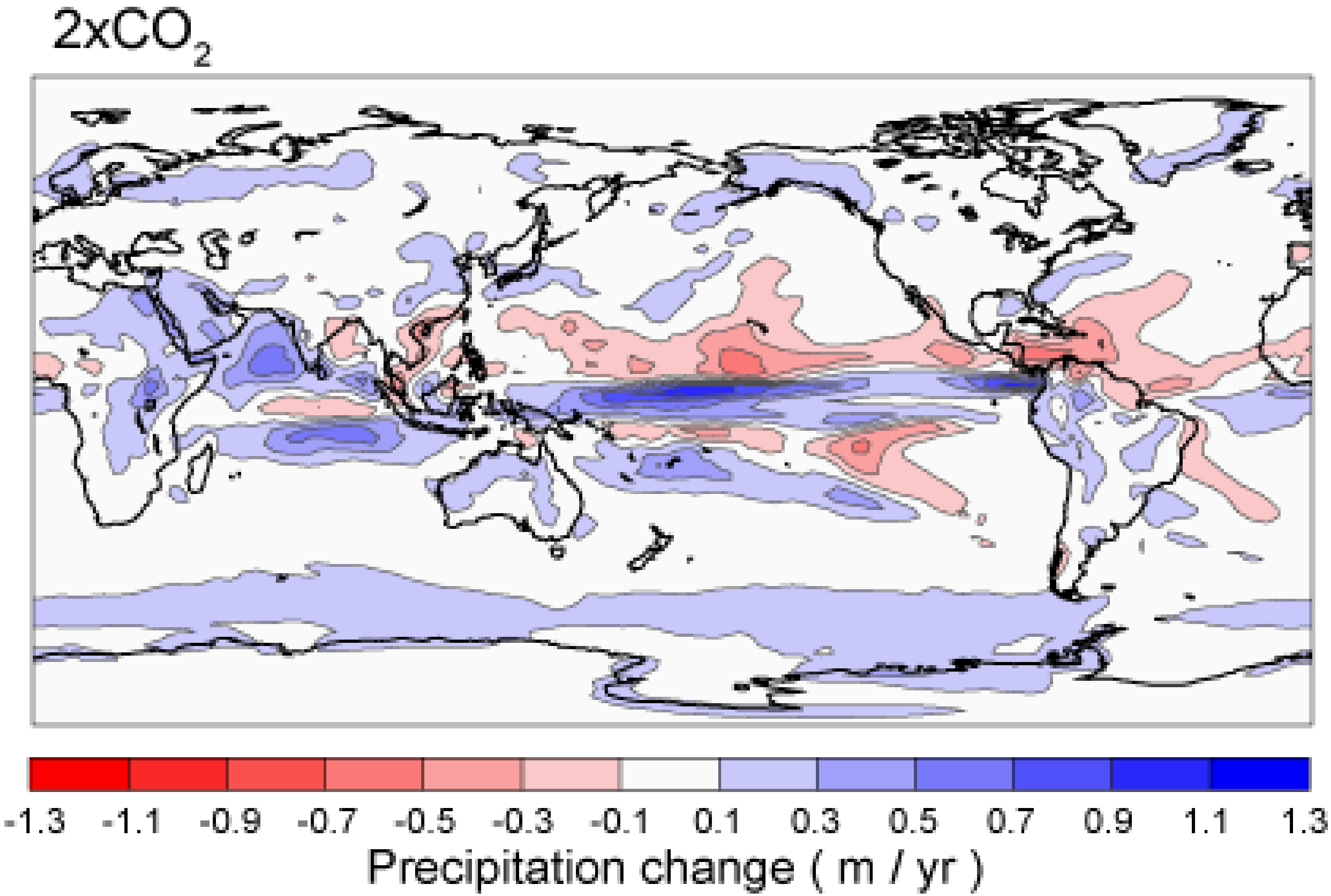
Temperature effects of doubled CO_2

with a uniform deflection of 1.84% of sunlight



Caldeira and Wood, 2008

Precipitation effects of doubled CO_2



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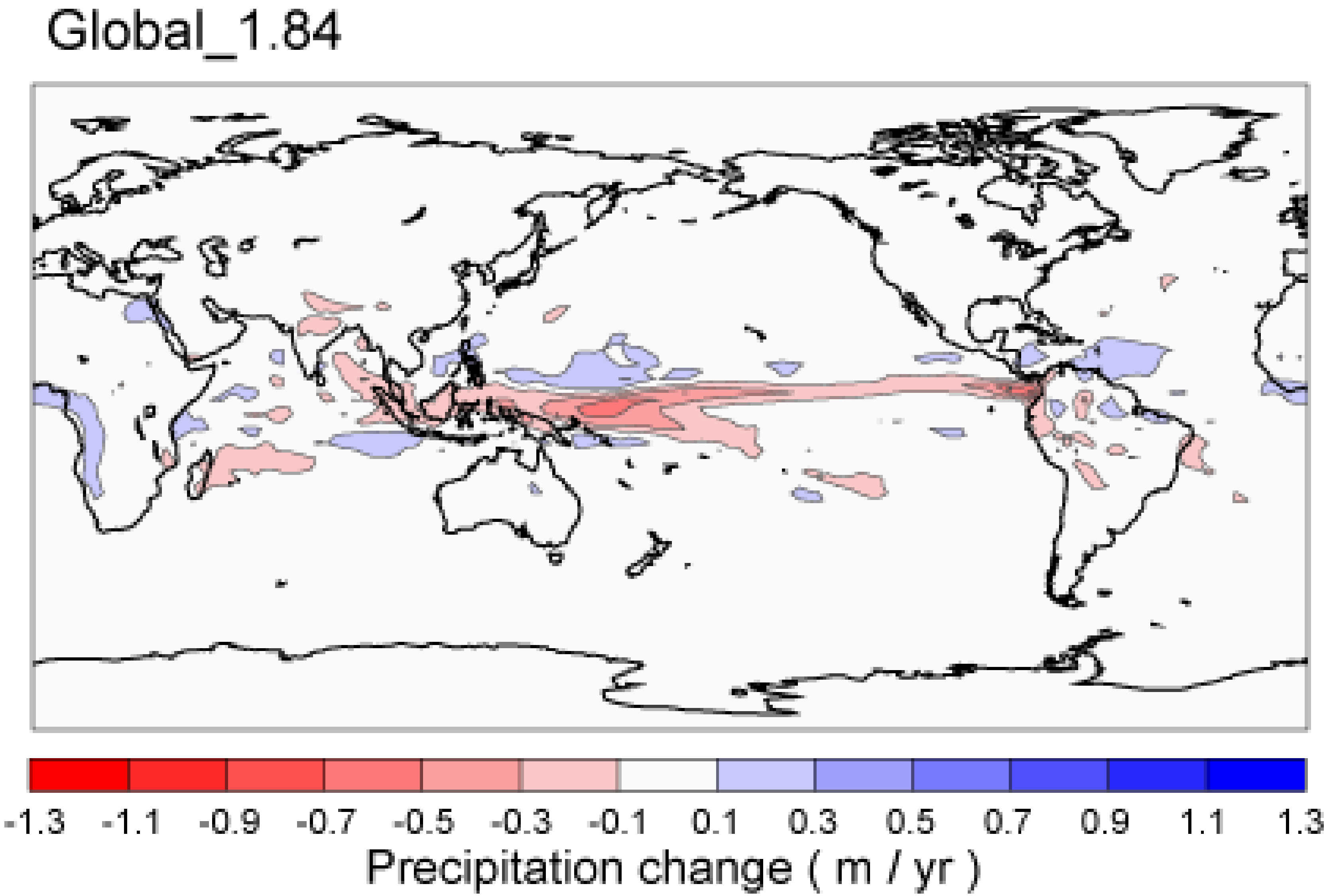

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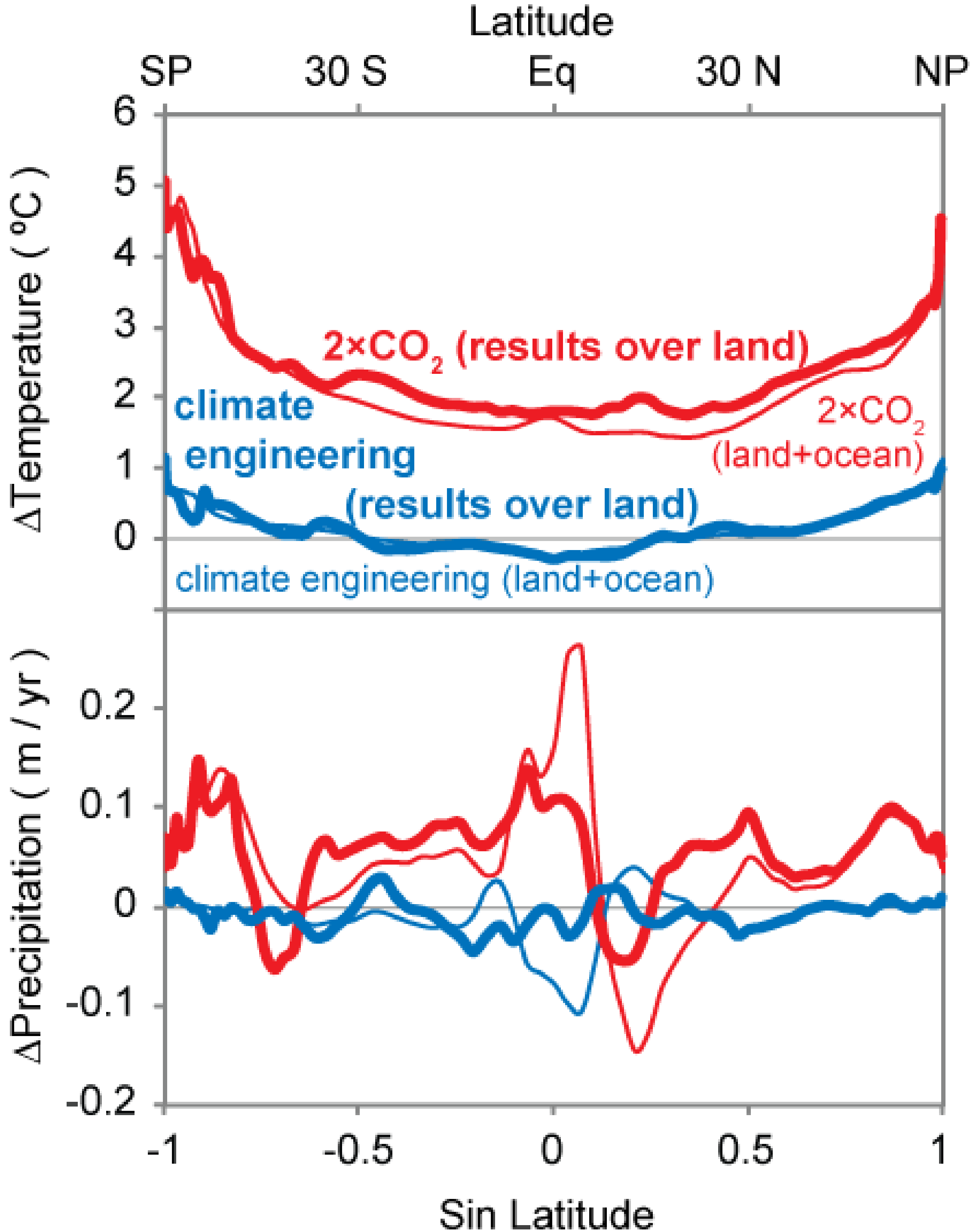


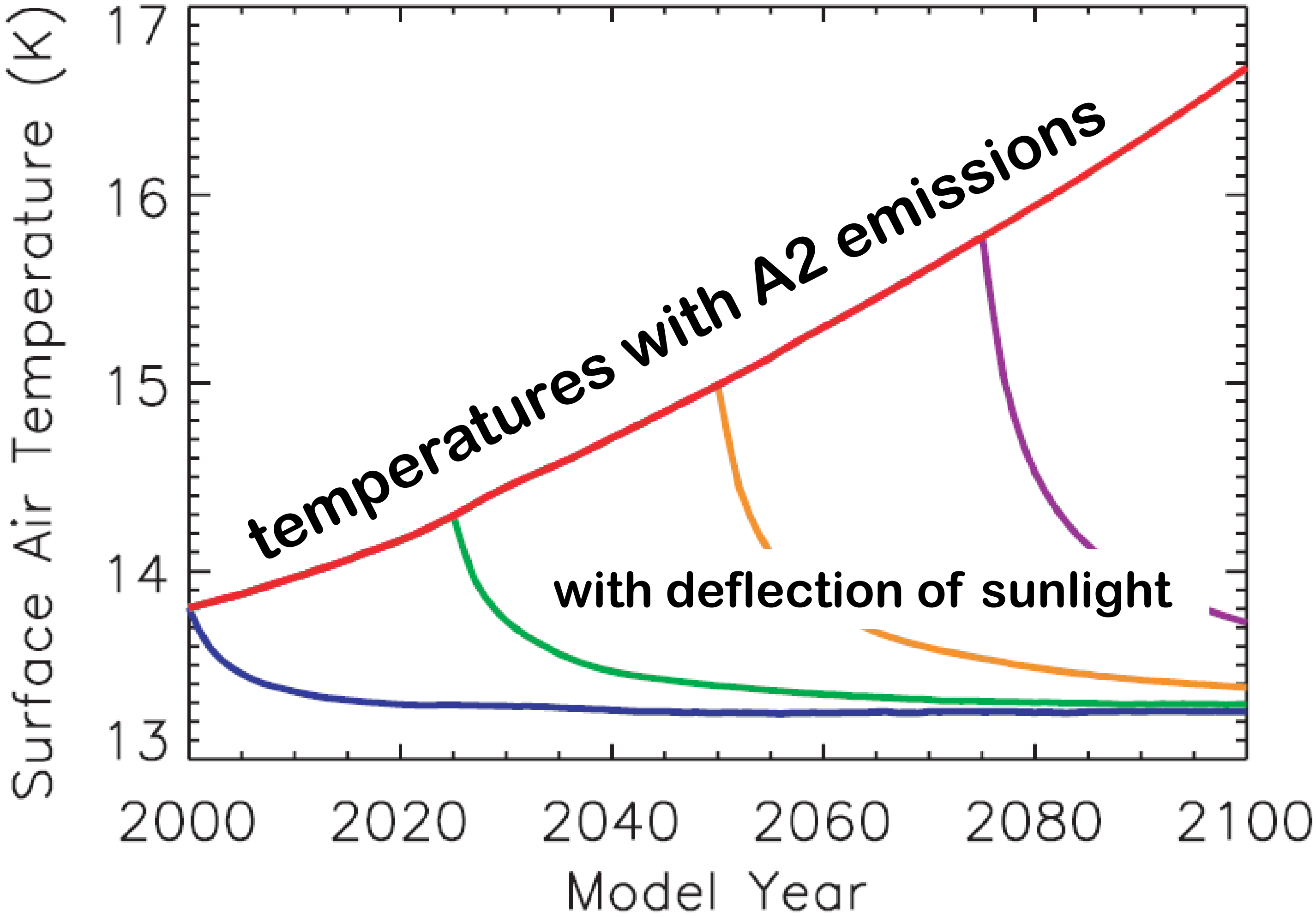
Deflecting 1.8% of sunlight reduces but does not eliminate simulated temperature and precipitation change caused by a doubling of atmospheric CO_2 content

Caldeira and Wood, 2008

Climate models indicate –

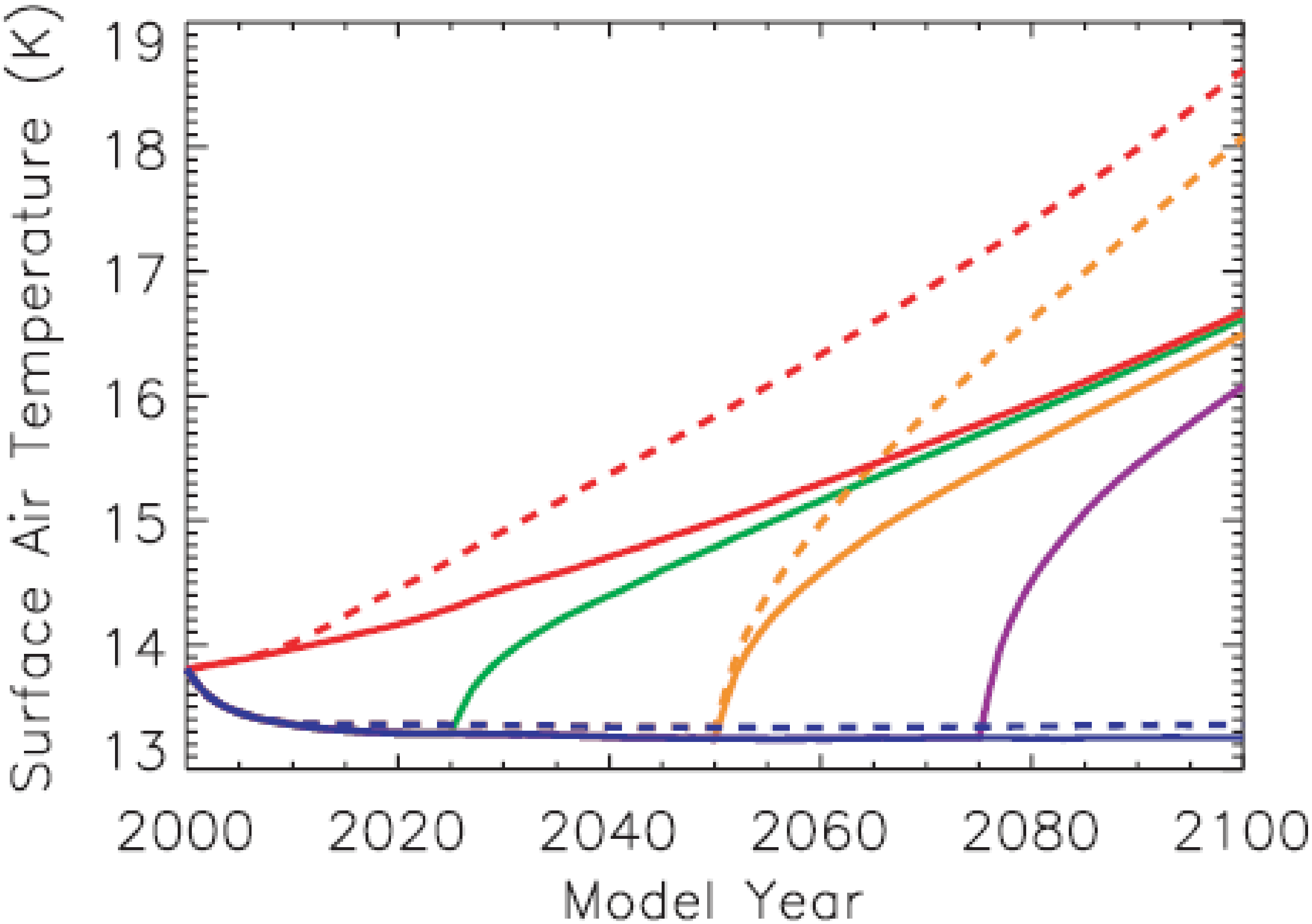
Deflection of sunlight can offset most climate change in most places most of the time

Climate intervention could cool Earth within years



Matthews and Caldeira (2007)

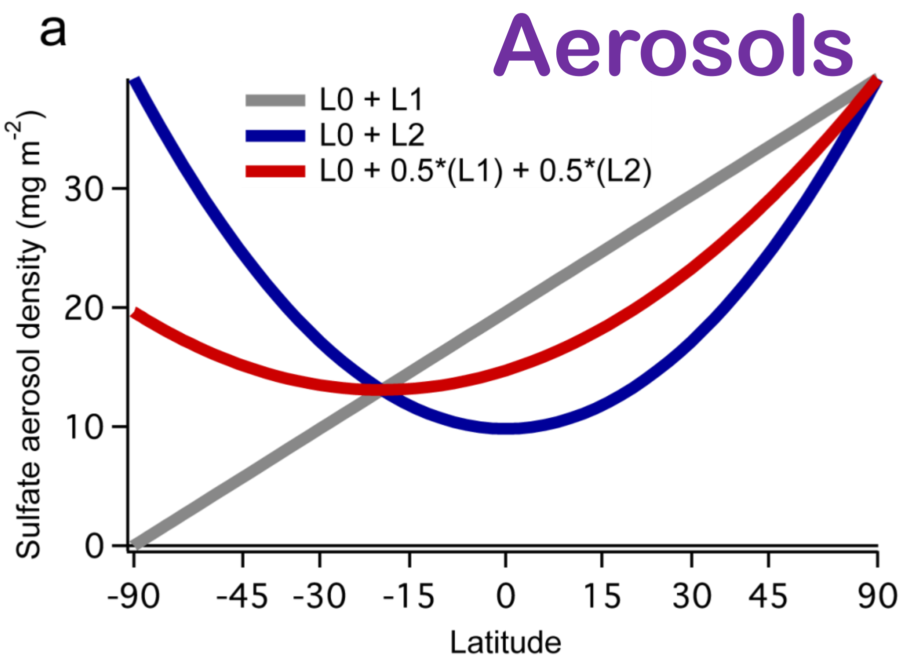
“Turning off” climate engineering could cause rapid warming

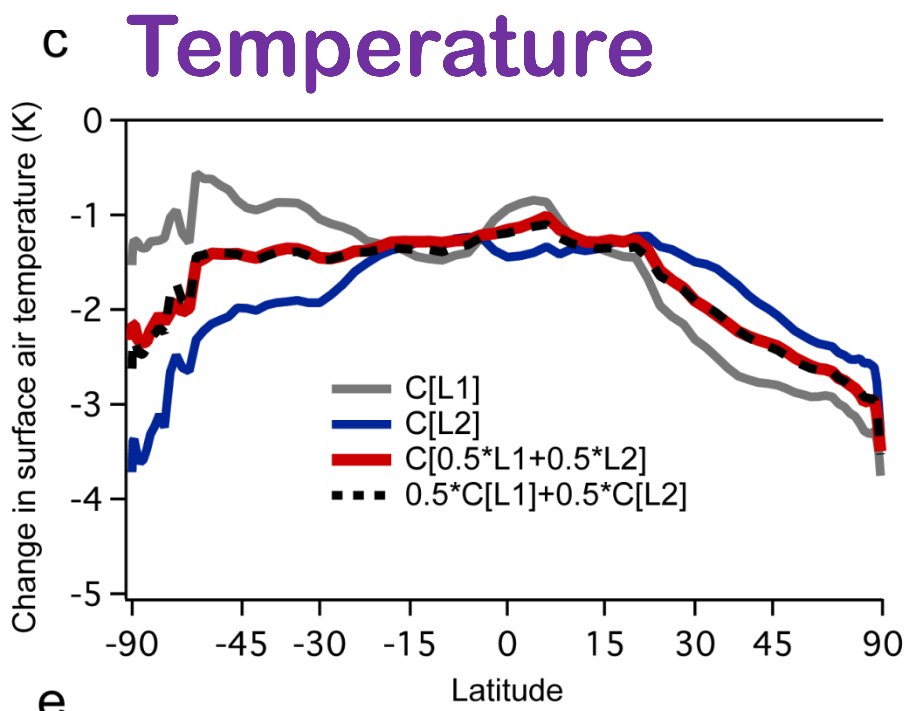


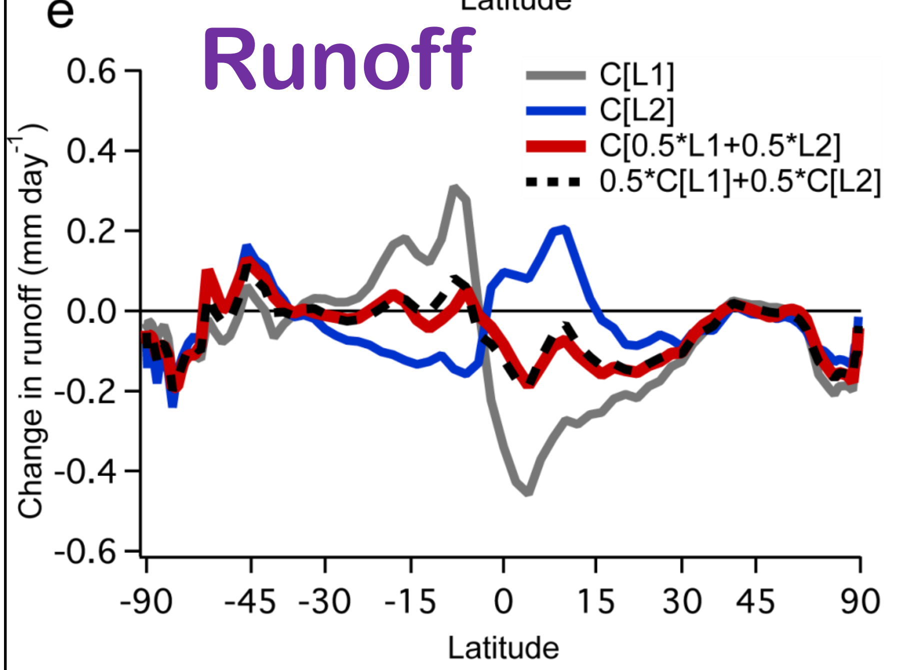
Matthews and Caldeira, 2007

Can the pattern of aerosols be optimized to diminish the amount of climate change?

Climate model responses to idealized stratospheric aerosol distributions



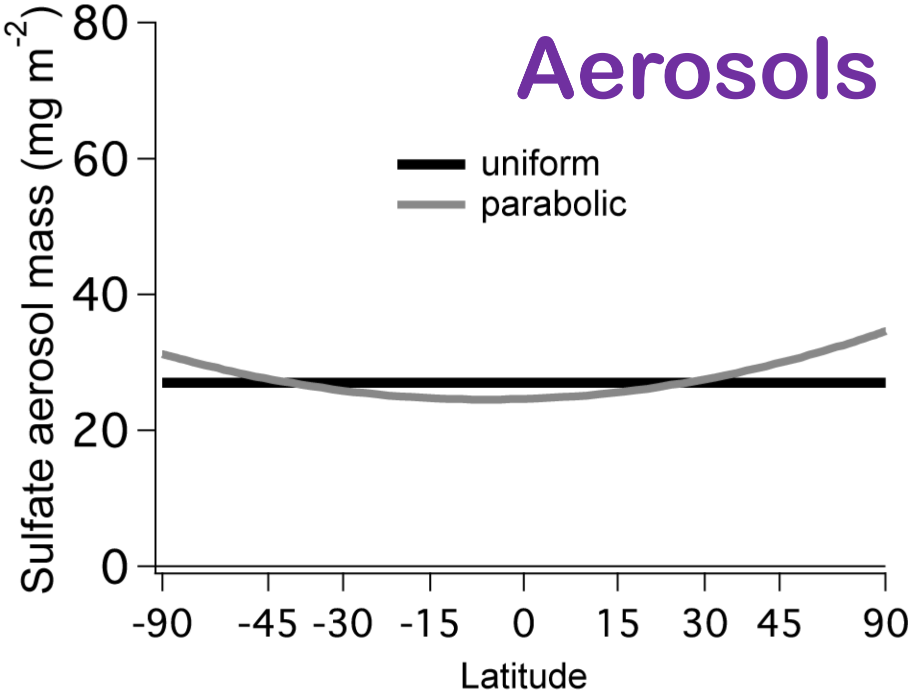


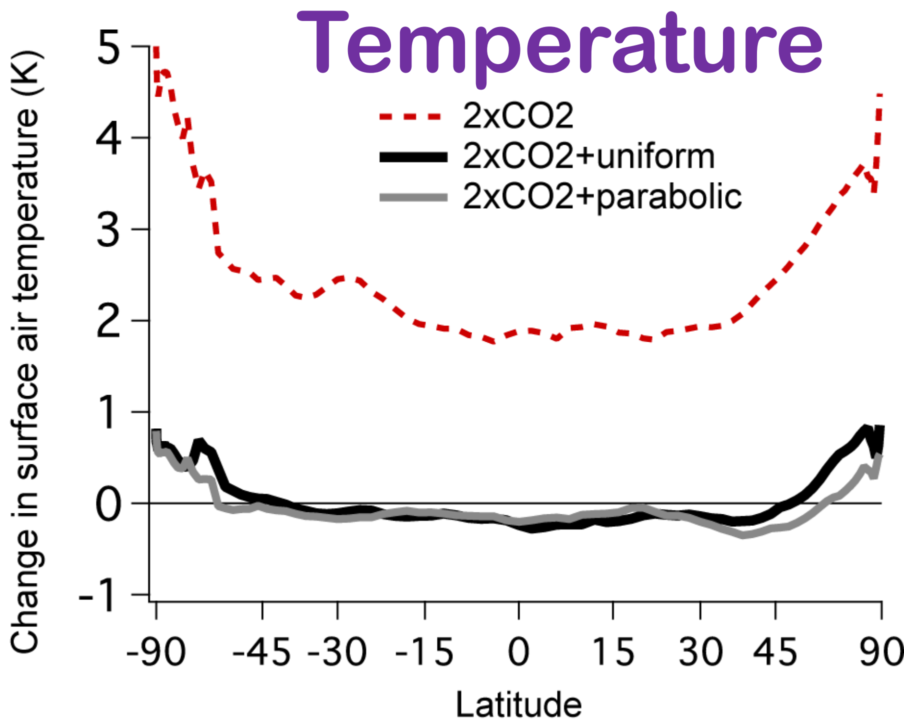


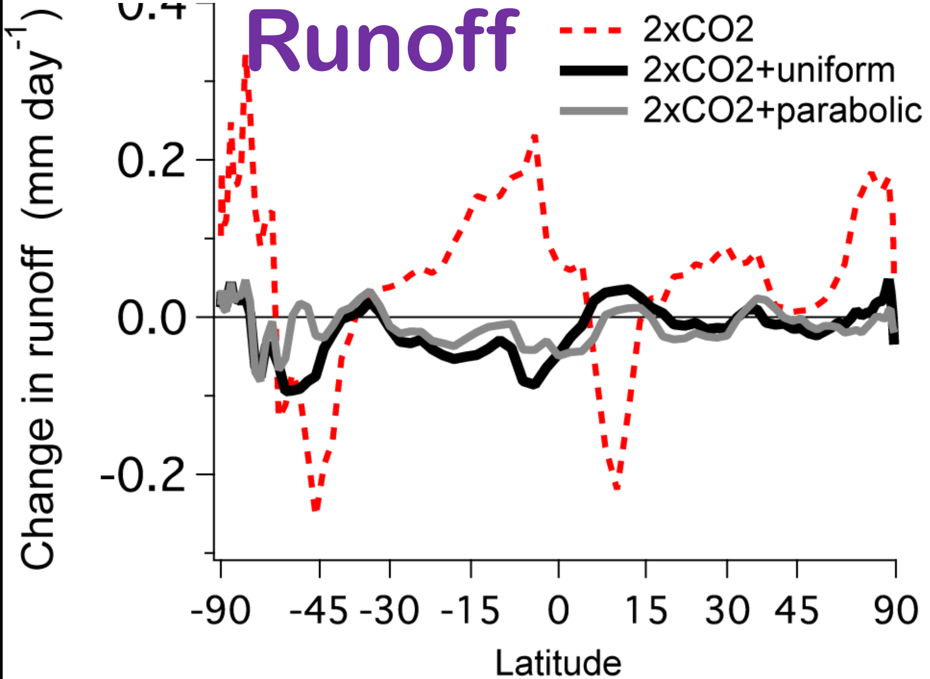
Climate response to a linear combination of climate forcings is similar to a linear combination of climate response to each forcing taken separately.

Ban-Weiss and Caldeira, in prep.

A combination of temperature and runoff changes can be minimized simultaneously

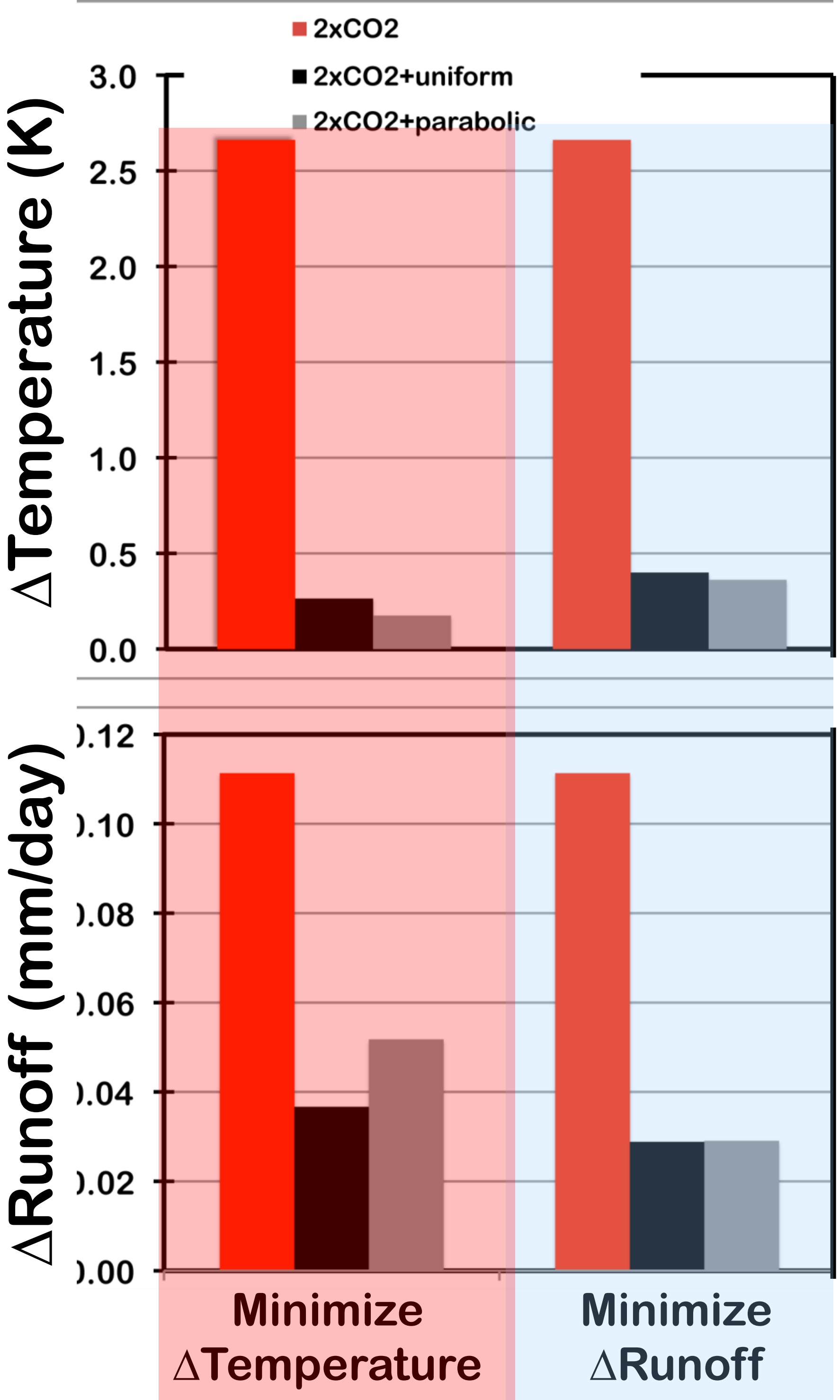






Ban-Weiss and Caldeira, in prep.

Approximate linearity of climate system makes it easier to find near-optimal aerosol loadings



$2xCO_2$

with uniform aerosol distribution

with parabolic aerosol distribution

rms differences based on zonal mean analysis

Ban-Weiss and Caldeira, in prep.

Climate models indicate –

Stratospheric aerosols can offset most climate change in most places most of the time

(for both temperature and precipitation/runoff)

But won’t the reduction in solar radiation hurt the biosphere?

Geoengineering and plant growth

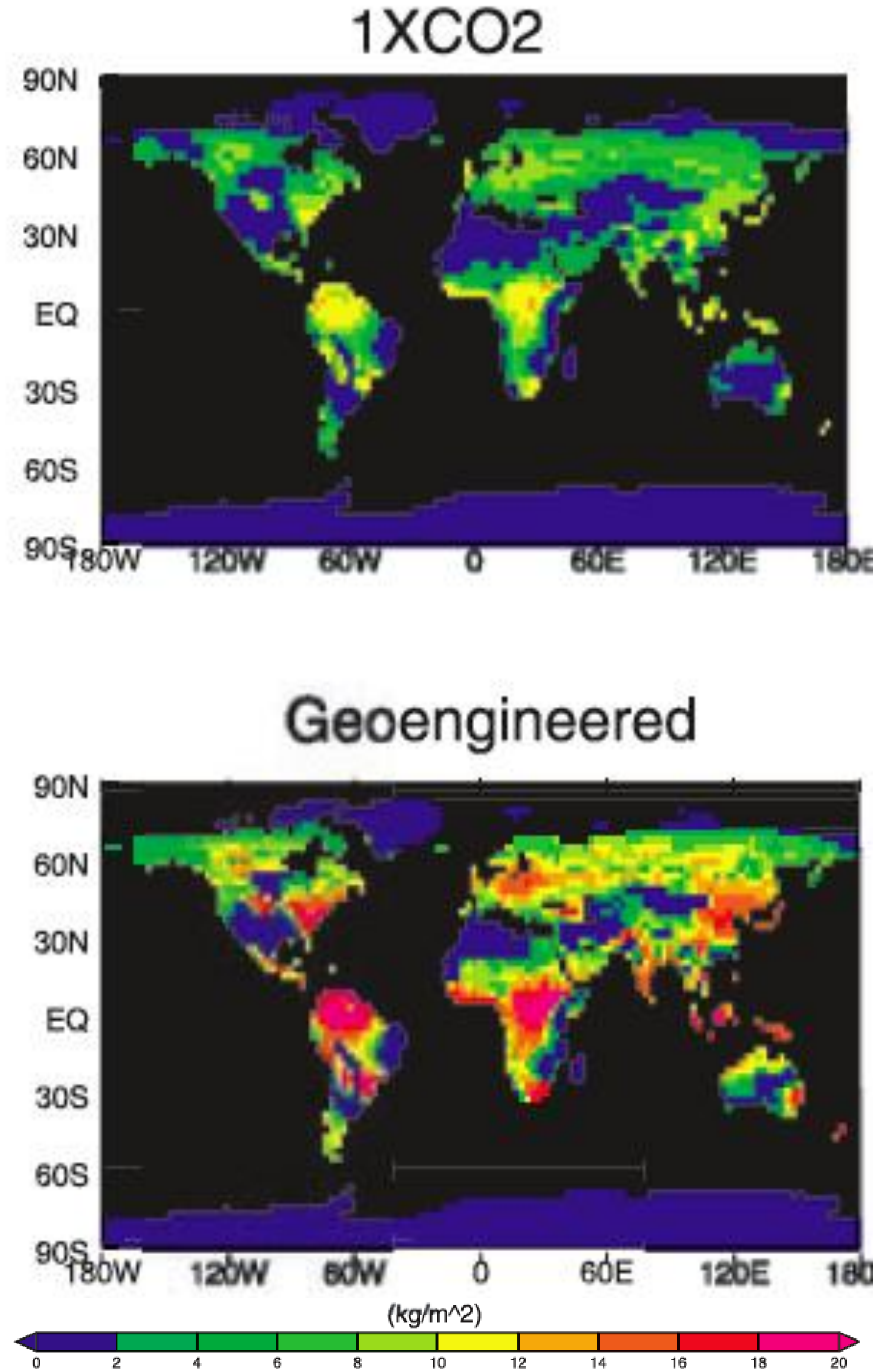


Figure 1. Total annual mean biomass simulated by IBIS in

In the model, plants grow much better in the geoengineered world than in the natural world.

Geoengineering results in CO_2 fertilization without the increased heating that leads to increased plant respiration

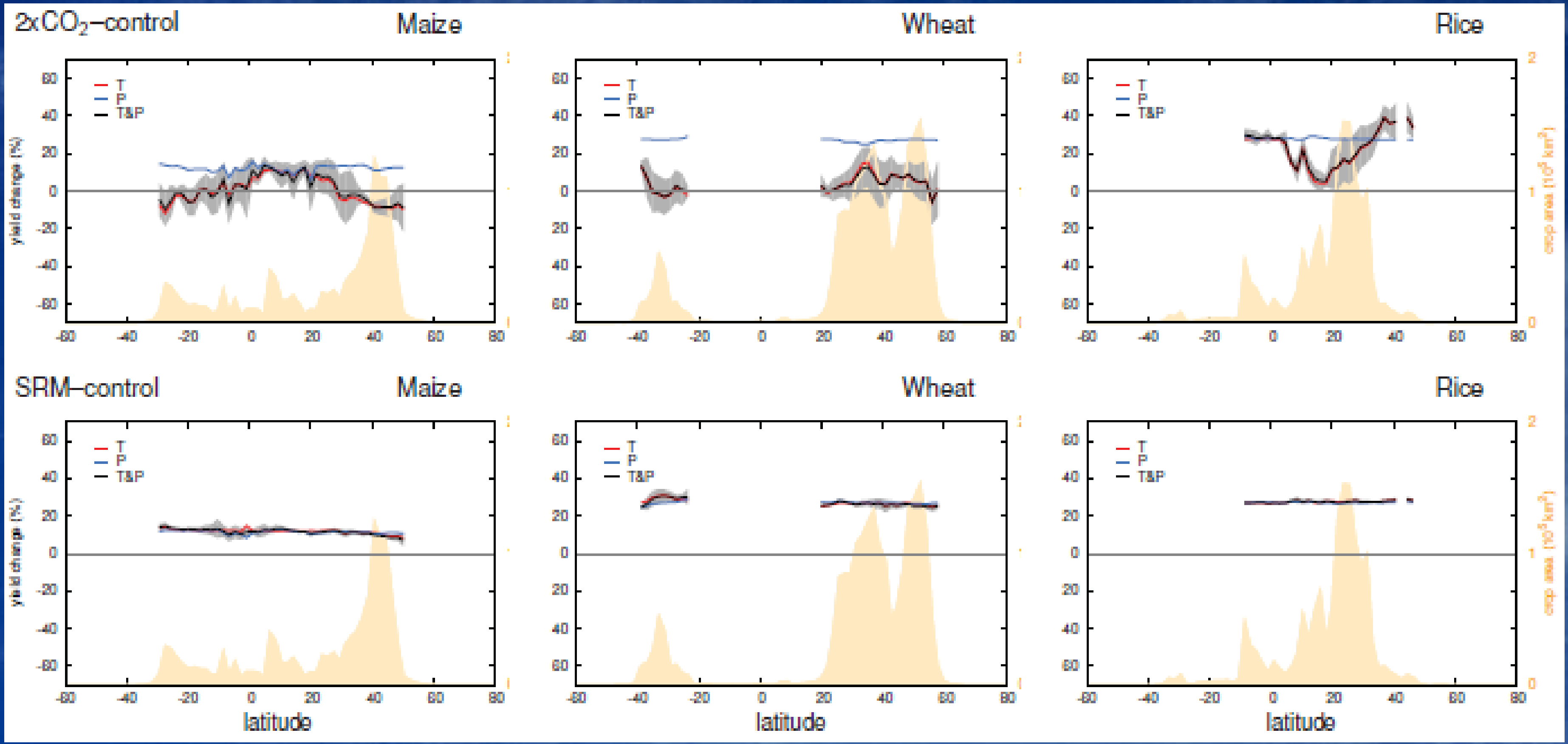
Govindasamy et al., 2002

% increase in crop yields in a high-CO_2 world without and with deflection of sunlight

	2xCO2 minus pre-industrial	2xCO2 + geo minus pre-industrial	2xCO2 + geo minus 2xCO2
Maize	-3	11	14
Wheat	6	26	21
Rice	19	28	8

From Pongratz, Lobell, Cao &-Caldeira, *Nature Climate Change*, 2012.

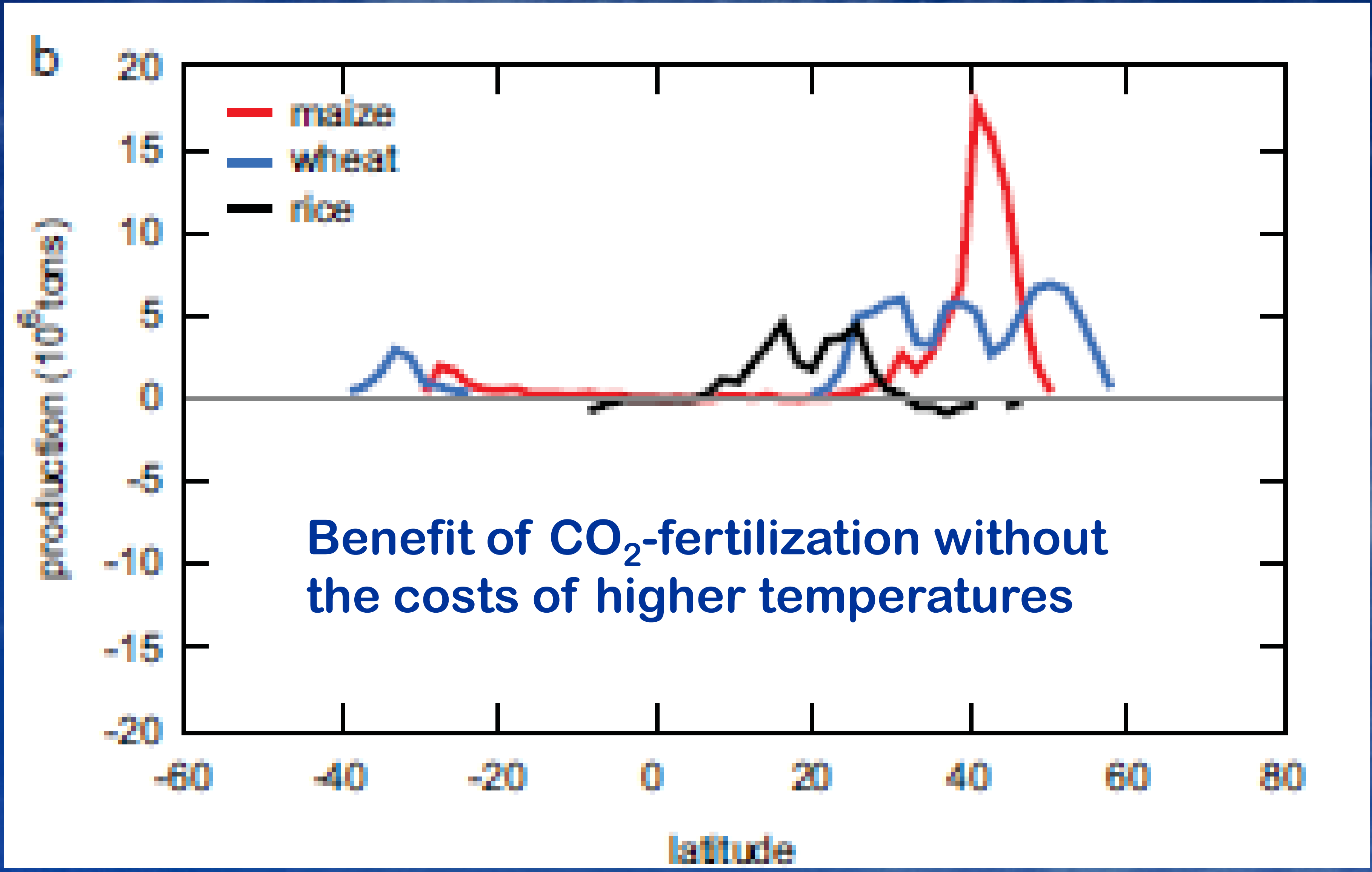
Crop yields in a high-CO_2 world without and with deflection of sunlight



Benefit of CO2-fertilization without the costs of higher temperatures

From Pongratz, Lobell, Cao &-Caldeira, *Nature Climate Change*, 2012.

Crop yields in a high-CO2 world without and with deflection of sunlight



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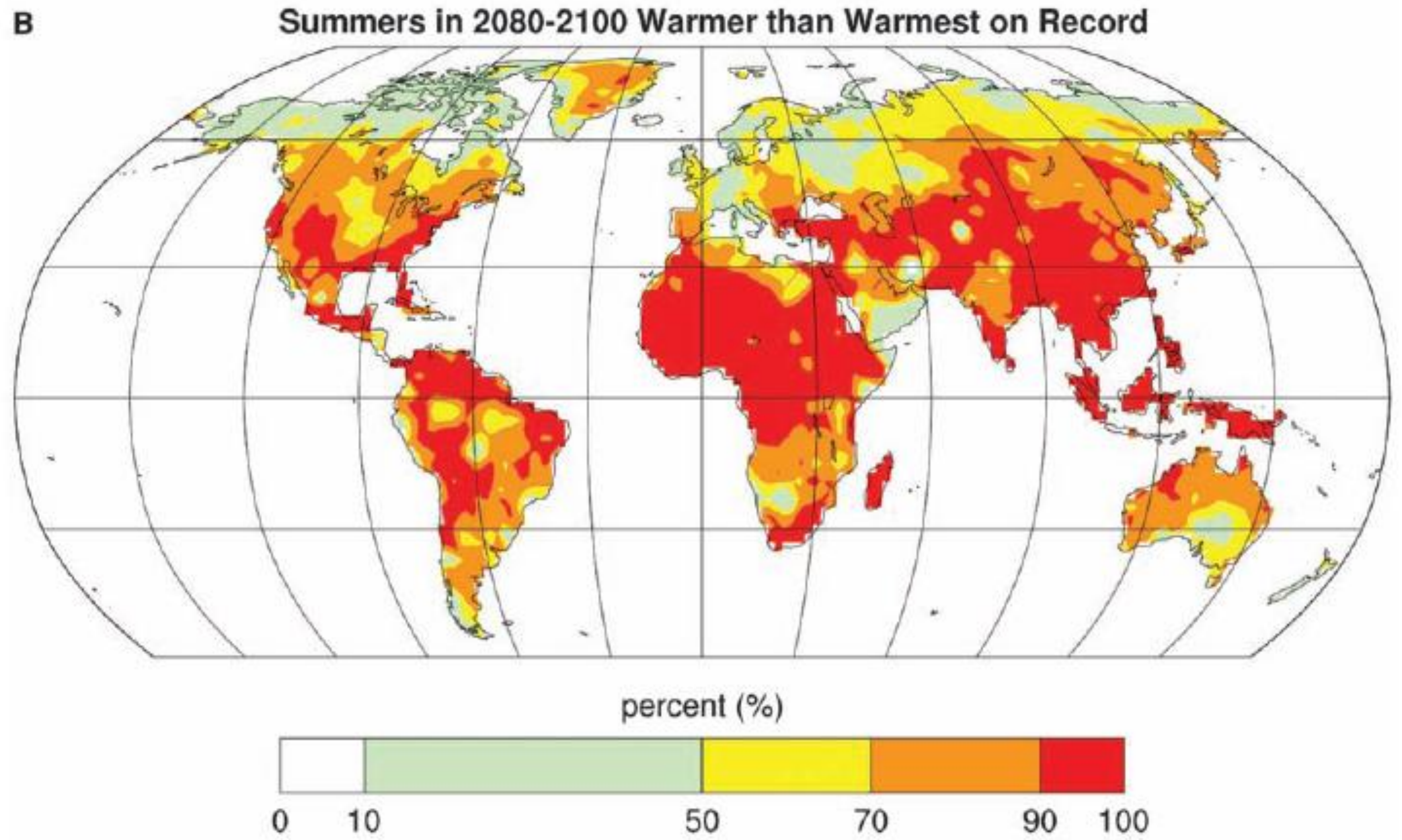

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Unanticipated outcomes

Reuters: David Gray

There are many sources of risk associated with climate intervention –

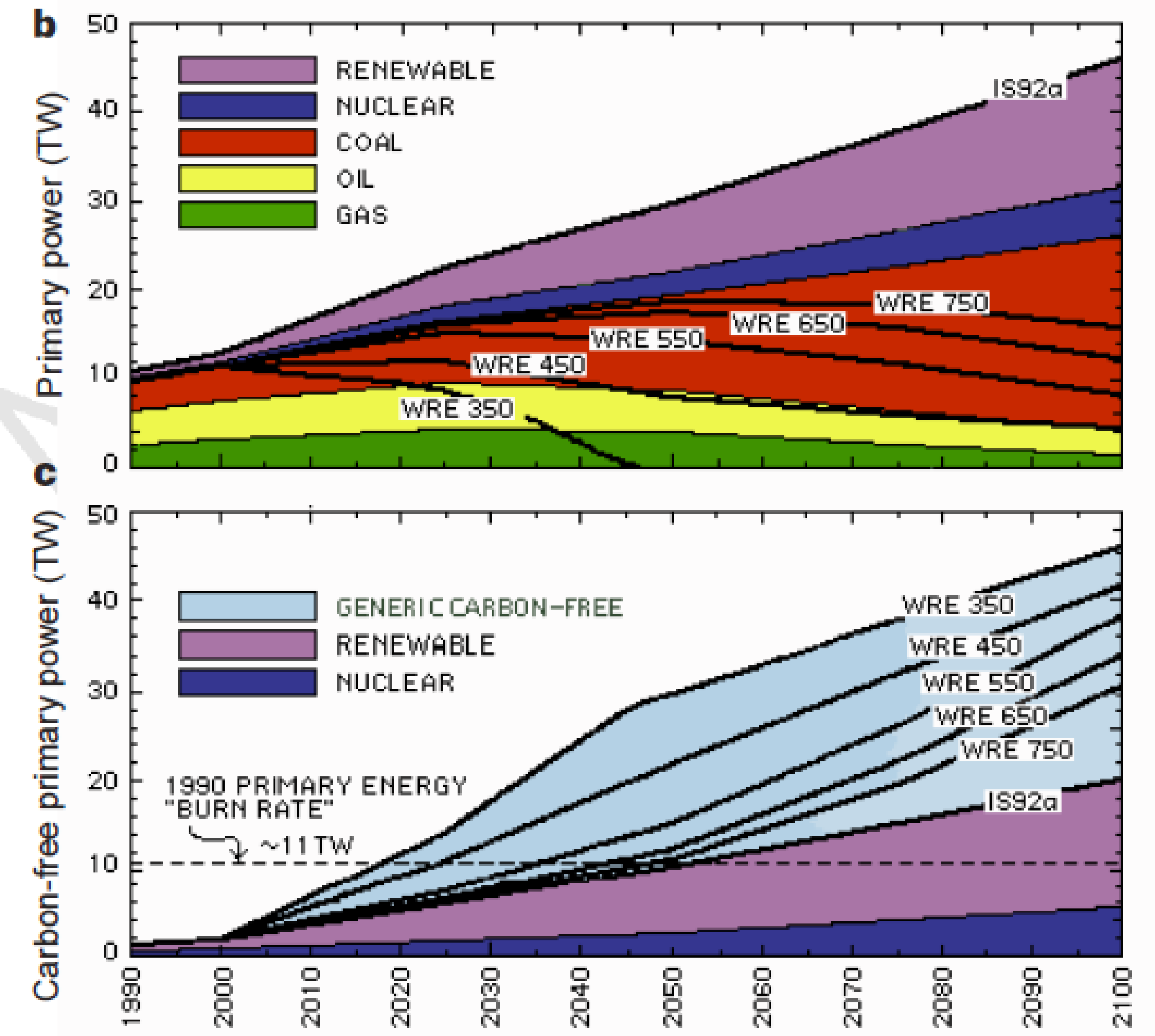
international political risk
risk of complacency
chemical risk
ecological risk
management risk
etc, etc, etc


Little knowledge
Increased risks
Potential for risk reduction

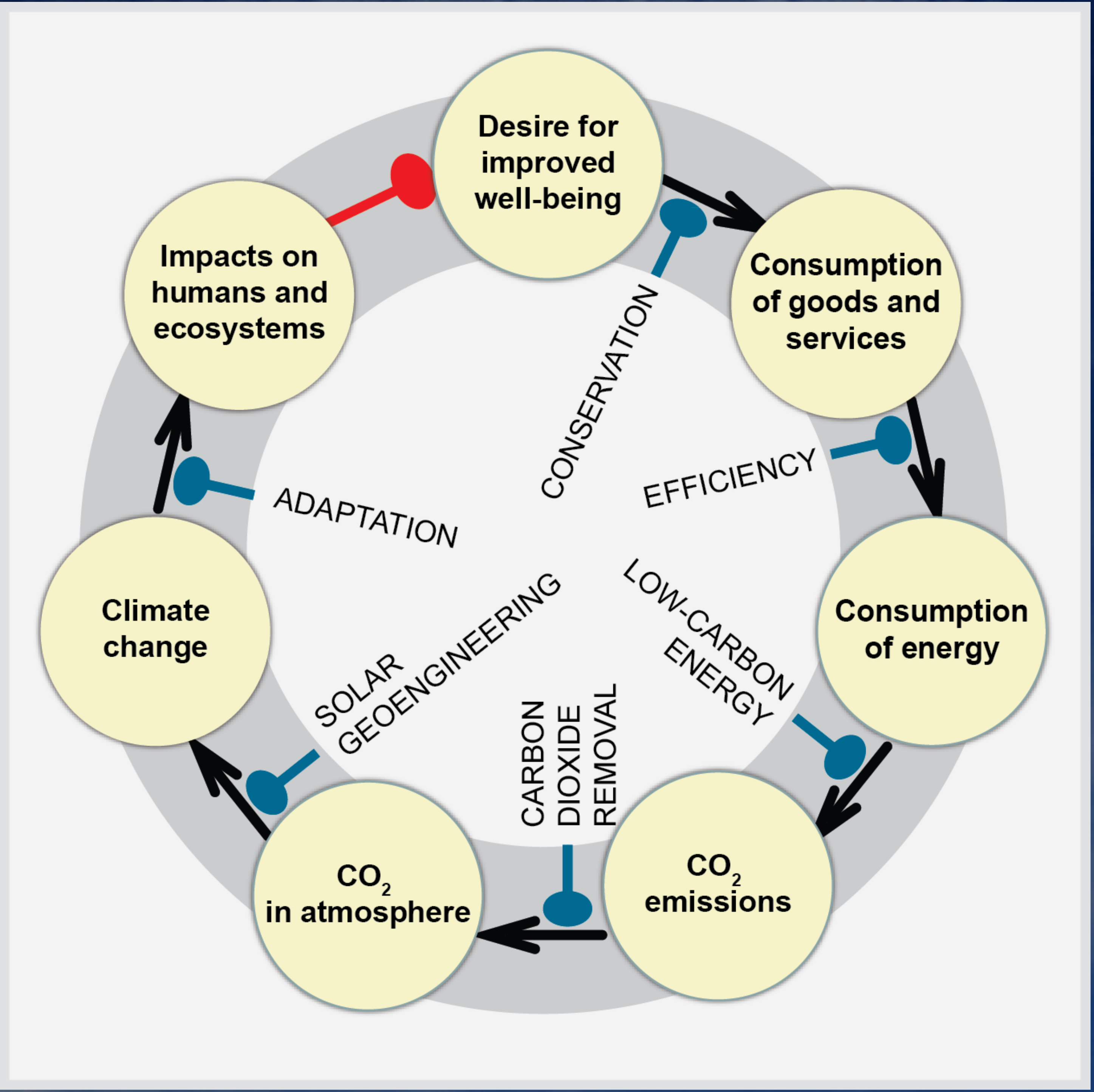
Intentional intervention in the climate system has the potential to reduce climate risk.

It is unknown whether it can reduce overall risk.

Massive amounts of carbon-emission-free power are required to stabilize atmospheric CO_2 content



Hoffert et al, Nature, 1998



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